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ABSTRACT

Papers on the acquisition and use of computers and telecommunications systems by colleges and universities are presented ("Information Technology: Instruction Is the Issue--An Introduction"; "The 'Star Wars' Universities: Carnegie-Mellon, Brown, and M.I.T."; and "Instruction and the Computer"). The first section describes developments at Carnegie-Mellon University, Brown University, and the Massachusetts Institute of Technology, which all have large investments in information technology. While the level of investment involved is too high for most colleges, the experiences of these three universities may be valuable to others, particularly with respect to issues of institutional planning and management. Ways that computers might be used to improve teaching and learning are also considered, based on proposals funded by the Fund for the Improvement of Postsecondary Education. Applications of the computer to instruction include: using computer simulations of light sources and detectors to introduce the beginner to optics at the University of Maryland, incorporating microcomputers into the curriculum at Colorado State University, the use of computers with hypertext-based systems at the University of Illinois, and Milwaukee Area Technical College's proposal to develop a new resource center and curriculum to support the needs of automation and manufacturing and metal working industries. (SW)

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Computers on Campus: Working Papers

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Edited by Marc S. Tucker

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CURRENT ISSUES IN HIGHER EDUCATION

Computers on Campus: Working Papers

Edited by Marc S. Tucker

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Marc S. Tucker is Director of the Project on Information Technology and Education. The Project is funded by the Carnegie Corporation of New York. Mr. Tucker's views are not necessarily those of the Corporation or its staff.

Information Technology: Instruction is the Issue

Marc S. Tucker

Any casual reader of *The Chronicle of Higher Education* knows that the use of information technology on our campuses is undergoing explosive growth. The news is easy to come by, but is as if delivered on the evening newscast—all in headline form. One institution is installing sophisticated telecommunications networks connecting every building on its campus; another is developing advanced computer workstations to serve faculty and students; and still another is requiring all its students to purchase powerful microcomputers irrespective of course of study. Beyond the headlines, though, there is a strange silence. There is very little in print about why these developments are taking place, what institutional leaders expect the benefits to be, what plans are being made to translate hardware investments into better instruction, how information technology is actually changing the lives of students and staff or the nature of the institution itself.

The reason for the silence is simple. Campus leaders most directly involved are much too busy making policy, designing systems, and managing implementation to write reflective articles for scholarly journals describing the fast moving events in which they are key participants.

The result is that those faced with making decisions about the use of information technology on one campus know surprisingly little about what others are doing, and even less about why they are doing it, what they expect to gain, or how they are approaching the problems they encounter.

Hence this *Current Issues in Higher Education*. There is written information about these matters, but it is not to be found in the conventional places. Committees are formed on campuses to decide what should be done. Sometimes they have written charges; sometimes they issue written reports. Proposals are written to firms that might be willing to underwrite equipment purchases or to public and private agencies that might be willing to fund applications to particular courses of study. Faculty and alumni are kept up-to-date on developments with occasional progress reports.

This *Current Issues* consists of sections of such documents tied together with a narrative that explains their origin and comments on their contents. In many cases, they were not meant to be polished descriptions—much less analyses—of the scene they paint, and should be read in that context. Working papers, by definition, are not finished products.

Nor, taken together, are they intended to be a comprehensive, or even representative, picture of the current scene. In the main, the documents from which the excerpts come originate from institutions I happen to have visited or which have submitted proposals to the Fund for the Improvement of Postsecondary Education (FIPSE), where I serve as an advisor. It is possible, even likely, that there are more creative, thoughtful, and interesting developments taking place than those reported here.

My purpose, however, is not so much to describe, as to provoke and stimulate, by giving the reader an opportunity to "visit" for a while with others struggling with similar problems in a variety of contexts. I will act as interlocuter, pointing out along the way the significance as I see it of points made in passing, or raising questions about points not addressed at all.

First, however, by way of establishing a context, I will indulge in a little speculation about the nature of the problems to which the colleges and universities are responding.

For a great many institutions the problem is that unprecedented proportions of the entering freshman class want access to introductory computer programming courses; in others, faculty and

Those institutions that decide to make these investments must find ways to translate the money spent into substantially increased benefits for students.

students together are overwhelming existing computing capacity with demands for access to word processing facilities; elsewhere, colleges are finding that their ability to attract top quality students is dwindling because they cannot offer attractive computing facilities, whereas those that can, find applications rising fast. Many large institutions are realizing that they can substantially cut the rate of growth in telephone costs if they combine voice and data transmission requirements into multipurpose digital transmission systems using sophisticated switch gear. And leading research universities worry that their ability to attract first rate researchers and students, as well as large research grants and contracts, may well depend on whether they have or appear to have a leading position in campus computing and telecommunications.

To a significant extent, then, competitive pressures are providing powerful incentives for institutions large and small, wealthy and financially hard-pressed, to spend very large sums on computers and telecommunications systems.

It is also true, as we shall see, that many colleges and universities are responding not just to problems, but also to a sense of opportunity. Many are developing ways in which the quality of education might be improved and the productivity of those who work in these institutions increased. It is important to remember, however, that the cost per student in higher education has for some time been rising faster than the rate of inflation. And so have tuition prices. This process will be greatly accelerated if the costs of acquiring large amounts of computer and telecommunications equipment are simply added to the current total, unless one of two things happens. The purchase of this machinery could permit the institution to reduce some other costs by the same amount, or could increase total funds received by an equivalent amount. The first is likely to happen only when we are talking about replacing current telephone systems with more advanced systems, and is not really relevant to our purpose here. The second could happen if the benefit to the student of the improved instruction offered was great enough to justify the increased tuition cost, if "wiring the campus" made it possible to extend the clientele of the institution beyond those who currently pay for its services (a possibility I will address later on), or both.

The challenge is straightforward. Those institutions that decide to make these investments must find ways to translate the money spent into substantially increased benefits for students. This means figuring out how this technology can be used to improve instruction, not in computing, but across the board. That challenge is the focus of this *Current Issues*.

The rest of this volume is divided into two sections. The first describes developments at three universities: Carnegie-Mellon University, Brown University, and the Massachusetts Institute of Technology (M.I.T.). These three, to my knowledge, outrank all others in the nation with respect to current scale of investment in information technology for instructional purposes—close to $200,000,000 all told over the next few years.

Because of that level of investment, the issues arising at other institutions often stand out in bold relief to these three places. While the level of investment involved creates opportunities that others will find out of reach, these hothouse environments have already gained much experience from which others might learn, particularly with respect to broad issues of institutional planning and management.

The second section looks at ways in which computers might be used to improve teaching and learning. It is based on proposals funded by FIPSE. Here, the "star wars" world of Brown, CMU, and M.I.T. is gone. Most of these proposals come from professors who knew little or nothing about computers a few years ago and whose interest is in improving their teaching of another subject about which they care greatly. The equipment they are using is widely available on college and university campuses. What is of interest is their ideas about the ways information technology might transform what they teach and the way they teach it.

The "Star Wars" Universities: Carnegie-Mellon, Brown, and M.I.T.

Carnegie-Mellon University

In October, 1981, the President of Carnegie-Mellon University, Richard Cyert, created a Task Force on the Future of Computing at Carnegie-Mellon University. An outsider might have been puzzled. CMU at that time already ". . . provided the most interactive computing per student of any university. [But] . . . those responsible for computing realized that the time shared approach was too expensive to provide the desired computer-saturated environment. The most promising alternate approach centered on using large numbers of microcomputers."[1] For such a large project, they needed a plan.

But why a computer-saturated environment? The answer lies partly in CMU's history and conception of its role. Though CMU was relatively small—5,500 students and 1,000 faculty—it ranked third among private universities in total dollar volume of industrial research. CMU's leadership had been convinced for years that computers would change the face of the workplace, and had dedicated themselves to placing the University in front of technical universities by taking a leadership position in computing: in part by making sure that students had maximum access to computers as tools to get their work done, in part by using computers heavily in research, and in part by doing leading edge work in computer science. The cost of expanding mainframe capacity to continue this strategy forced the search for alternate hardware configurations.

What is noteworthy, however, is that the plan commissioned by President Cyert did not focus on hardware.

He wanted, he said, ". . . a broadly based view and a sense of perspective about where we want to go . . . a structure that can operate as a planning framework for continual modification and updating. It will not do to have to evoke in 1983 a new Task Force for the Real Future of Computing at CMU."[2]

The Preliminary Report of the Task Force was issued in February, 1982 (to my knowledge, there is no final report). What follows is excerpted from that report:

Preliminary Report

The Task Force for the Future of Computing at CMU (TFFC) was created by President Cyert in September 1981 to formulate a view of what computing at CMU should be like in the mid to late eighties.

Basic Positions Underlying this Report

Committees to study computation are a regular feature of university life, both here and elsewhere. Commonly, major concerns are first with equipment and second with economics—with cost/benefit analysis in the narrow sense. The Task Force believes that a more useful focus for its own analysis is based on the following positions.

The baseline is a substantially increasing use of computers. The starting point for analysis might be whether there should be any increase in computing. But the neutral assumption is, in fact, that computing will continue to increase substantially, with or without comprehensive planning. Both growth of computation in the external world and the already deep involvement of the university drive CMU along this path. The important issues are then how to shape this growth and whether to seize the moment to make a dramatic move to accelerate the increase in computational facility to attain some worthwhile goals.

We take the position that a substantial increase in computing at CMU is fundamentally good. By a substantial increase we mean that most of the community would no longer find computing a scarce resource; terminals would be available when needed, response times adequate to most tasks, storage sufficient, and printing quick and convenient.

We believe in the potential of this increased computation not only to help all manner of separate activities, each in their own way, but also to support new modes of integration and community. Although the ongoing computer revolution has often failed to achieve these goals, and we share with many in the CMU community concerns about the effects of letting the computer seep further into our lives, withal, we believe the promise is great and the benefits clearly outweigh the dangers. We believe our energies should go into finding the right way to proceed and to do a high-quality job.

We take the position that a substantial increase in computing at CMU is fundamentally good.

The analysis should focus on designing an environment and predicting impacts. Our goal is to set up guidelines for the growth of an appropriate computing environment. These guidelines address what should come first, major advantages that could accrue to CMU, impacts on all segments of the campus, and identification of negative side effects with ways to abate them.

Our guidelines do not prescribe total plans for action (e.g., what equipment, what vendor). But we believe that such specific plans should grow from the design of the environment we begin to outline.

Analysis should be in terms of general types of computational facilities. We believe that the important issues can be discussed better by avoiding details such as vendors or specific equipment.

This view implies little attention to relative costs. While we have no quarrel with economics, narrowly defined cost-benefit analyses shift attention away from how large changes in computation will affect the entire campus community. Furthermore, if two pieces of equipment or software are sufficiently comparable to make a cost-benefit comparison valid, then choosing between them is probably an implementation decision better left until we have defined the total environment we want.

Behind this position is an assessment that large amounts of computational facility can be acquired by CMU within costs that are acceptable, due in large part to the radically decreasing cost trends in the industry. Thus, economics is not a primary concern in our discussion.

The Issues

We now present the issues we believe are the most critical to our computational future over the next decade.

1. Access to Computational Facility

Gaining access to computational facilities . . . involves making contact with hardware and software (e.g., a terminal and a port), discovering relevant tools, and learning how to use them. No matter how effective the computational tools themselves, gaining access is an impediment to the task at hand. If computation becomes a much larger part of our lives, good access, broadly defined, becomes absolutely critical.

The position of the Task Force is that effective expansion of computation must include generous resources and attention to making access easy and pleasant. This position has the following consequences:

- **The campus must have a high-quality local-area computer network.** The network must provide every user with direct access, from his own local access device, to all resources on campus available to him. The Task Force believes this is the single most important technical step that can be taken to enhance the computational environment of CMU. The network should also extend beyond the campus boundary so that access does not decline or disappear when working at home. (We recognize the technical difficulties here).

- **There must be good means for discovering available computational resources.** A multitude of computational tools exist both in the Computation Center and scattered through the community. There needs to be an information system of sufficient scope to index all these tools. This information system itself must be universally accessible, presumably both on-line, over local and remote networks, and in hard-copy form.

- **There must be access to appropriate data bases.** As with other organizations, CMU finds essential its accumulated information: libraries, accounts, inventories, space occupancy, student and personnel records, schedules of classes and events, alumni records, proposals, and more. Enhanced computation can provide access to such in-

formation for anyone with a legitimate interest (with due regard for privacy and security). The benefits to CMU in increased efficiency, accuracy, responsiveness and community would be very large.

• **Good documentation and human consultation are essential for access.** Interaction with knowledgeable people lies on a continuum with good documentation—both are needed in some mixture to obtain good access.

Ideally, good documentation of all facilities should exist in a variety of modes (on the computer as well as in mass-printed or demand-printed form), and at a variety of levels, especially primers for beginning users in addition to exhaustive system descriptions.

We have purposely placed access first on our list of issues. This is primarily because enhancing computation means enhancing computation usage, which means good access. However, we are also responding to the universal cry of frustration we have heard from the campus community about the current state of access, including all the issues discussed above. This frustrating current state was also the major cause of cynicism and doubt that CMU could implement a truly beneficial major expansion of computing.

In an effective computer-intensive environment, access must be easy, reliable and pleasant—even gracious. This is an absolute requirement for any major increase of computation, far more important than, say, how to package computation (e.g., as personal computers). A good campus-wide computer network plus a good organizational framework for the other aspects of access would provide a basis for letting CMU grow into an immensely productive computational future. Failing to provide this will almost surely lace any other scheme with painful frustration.

2. Computation and the Educational Process

The computer is a tool—a means, not an end—to be used by the instructor when judged valuable. Like the book, it is powerful and has particular usefulness in the instructional setting. Again, like the book, it can be used to convey great wisdom or immense trivia. More than the book, computers can get in the way of education if access is difficult and use is tedious and time consuming, or if the student comes to use the computer inappropriately.

• **Vastly increased computational facility can be a major aid to education.** The uses of modern computation range from the management of education (grades, assignments, scheduling), to information display in the classroom (dynamic situations), to text-processing for writing (both generally and in composition courses), to problem solving in data-rich (social science) and computation-rich (engineering) areas, to tutorials in drill and practice domains (e.g., solfege in music), to simulations (engineering), to exercise checkers (proofs in logic), to design tools (engineering), and much more. The sophistication will increase with time, and in the end it may rival the book in its impact on education.

• **The use of computation will be diverse and extremely uneven.** Greater availability of computers should not create expectations that everyone will use them. Our view is that the extent and variety of computer use for education will be impressive, but that certainly it will not be used everywhere.

If computation becomes a much larger part of our lives, good access, broadly defined, becomes absolutely critical.

Furthermore, new tools, however useful, do not change the fundamental role of the teacher in choosing freely how best to educate, without distracting pressures either from climates of opinion or from direct administrative expectations.

• **Access to robust computation is absolutely critical when computation is woven into education.** Most educational facilities—classrooms, books, paper and pen—are extremely robust, and even when catastrophe strikes (the heat goes off, a book is lost), substitute arrangements are manageable. The computer is not so robust, and, as described above, access is a real problem. Locking into this technology means that failures in the technology can become failures in instruction. Thus, major expansion in computation for education must include generous support of robustness and access.

Low reliability and poor access are especially destructive for individuals being introduced to the computer, not only because they are unable to work around problems in the short term, but because their initial problems can affect their long term view of computation. Students strongly told us that initial bad experiences had really put them off, and argued strongly for better attention to new student users.

• **Computer literacy is an important educational goal.** Literacy—narrowly, being able to read—can be made to carry a broader meaning: Being able to use a basic intellectual skill competently and intelligently, though not with mastery or scholarship. Literacy in some areas (e.g., writing, mathematics) is considered an essential component of becoming educated. We believe that computer skills should be added to this list.

Computer literacy is not equivalent to learning to program, but is different in at least the following ways: First, using a computer often means not programming, but using available tools—editors, electronic mail, statistical packages, simulators, computer-aided-design systems, data base systems, and so on. Using these tools intelligently requires skill, together with knowledge of when to use them appropriately. Second, using a computer effectively involves more than just local skills for using particular languages or tools. It requires understanding the fundamental nature of the computer, what kinds of things it can and cannot do. Third, if the role of computation is to increase qualitatively at CMU, computer literacy must include competence in the local computational facilities. This part of computer literacy is in fact an important part of good access.

Computer literacy is not a separate educational objective. If computation becomes more intensive in our environment, then we must convey to our students, as part of their education in all areas, the difference between intelligent and inappropriate use of the computer.

Without entering into the design of curricula for computer literacy, we believe that many different devices are appropriate for different functions—continuously available short courses to introduce the tools in the environment, diverse special-purpose courses offered by a variety of departments, computer-relevant topics integrated into other courses, on-line self-teaching aids for acquiring new tools, as well as regular courses in computer science.

• **The social dimension of computation.** Much speculation exists about the social effects of greatly enhanced computation, especially at the undergraduate level. Much of the speculation is evoked by the notion of each undergraduate having a personally owned computer. There is fear that this will isolate students, who will spend all their time interacting with their machines and not with other persons; also that officialdom (including faculty) will penetrate too deeply into students lives.

Attention must be paid to social questions, even though the nature of the questions will only gradually emerge. We make the following recommendations: First, the computer should not be restricted to the world of work; it is a general aid to living like the telephone and the television. As with these other aids, there will be a tendency towards overuse which must be counteracted not by restricting the use of computers, but by helping students understand the increasing societal role of the computer, including both its powers and its limitations. Second, much computing should take place in social settings. Terminal rooms are places of learning, communicating and socializing. Such places must be pleasant and conducive to such activities. When terminal rooms are crowded, noisy and laid out only for person-terminal interactions (all charges we heard repeatedly about the current scene), then the good things happen only fitfully at best.

Literacy . . . can be made to carry a broader meaning: Being able to use a basic intellectual skill competently and intelligently, though not with mastery or scholarship.

Making computation readily accessible implies putting it near or in residences. But there are problems in placing devices, which may be hot, noisy, and space-taking, into an already crowded residence world. Even beyond these mechanical aspects, computers may violate space that is now "where one gets away from it all." Solutions may exist, but they can be expected to be costly. We recommend that these problems be taken seriously and that, if necessary, resources be diverted from

. . . Much computing should take place in social settings. Terminal rooms are places of learning, communicating and socializing.

the computers themselves to support modifications to student residences or provision of auxiliary working spaces.

3. Management of the Computational Facility and its Expansion

Classically, computation is organized in a university in a small, centralized administrative hierarchy, abetted by an advisory committee, with essentially no integration of independently supported research computation. The proposed fully-networked CMU environment would be very different. The set of significant decision makers will be of the order of fifty to sixty, and will include members of almost every department.

The position of the Task Force is that effective expansion of computation depends fully as much on enlightened management as on high quality technology. Based on this view, we believe:

• **Sufficient resources must be provided to build and maintain a first-rate infrastructure.** In the recent past, CMU seems to have followed a policy of preferentially putting resources into equipment rather than support services. This imbalance must be ameliorated if a first-rate infrastructure is to be built.

• **The Computation Center should play a strong role in creating an environment for decentralized systems.** The Computation Center should encourage individuals or departments to develop and control local facilities, and to provide services to the community, as appropriate to their special research and educational roles. Similarly, the Computation Center should concentrate its energies on creating central facilities where central control and action seem most appropriate, e.g., networks, mass storage, or large acquisitions of common equipment.

• **The Computation Center should manage by incentives.** Even with greatly enhanced computing, resources will always be limited compared to all the tasks it would be nice to do. A great deal of these resources will be controlled by the Computation Center. In so far as possible, management should be by incentives—by making it pleasurable and profitable for people to use the facility in the ways that fit into the general plans of the center. This use of market mechanisms is a central means by which the goal above might be satisfied, and is to be contrasted with management by edict, which simply specifies how users must behave.

• **There must exist a continuously updated public plan.** Since decision making is dispersed, coordination requires an explicit and regularly updated plan. Such a plan should provide at least a common view for all decision makers of what computation currently exists and what is solidly planned. Even this minimal planning in widely accessible form would be an immense aid. The responsibility for formulating and updating this plan should fall equally on all of the decision makers, and not just on the Computation Center.

• **Expansion must be managed without major disruption.** Good organizational support should precede technological expansion. Publicized plans should be laid out to enable all to plan their own adaptations to change. Expansion should be conservative in preserving past facilities for backup, providing contingency resources to smooth over difficulties. High risks should not be taken without the participation of those affected.

4. The Rewards of Leadership

By advocating a substantial increase in computation at CMU, we are advocating that CMU lead universities into a world saturated with computation.

• **Large payoffs come from being a leader.** Leadership has its price, but also its rewards. There are direct payoffs for those involved in leadership, but also rewards for the institution more generally. First, leadership engenders the ability to gather the resources and the talent to do great things in the area of the leadership itself. Second, leadership and excellence in one area often translate into a general ability to generate resources and aid for adjoining areas and for the institution as a whole.

Thus, if CMU's development of computation is sufficiently prescient and responsive as to attain a position of leadership, then many rewards follow. Specifically, many of the resources necessary to carry out development can come from external sources, interested in learning about effects of intensive computer use in society.

In this respect, CMU is currently exploring the possibility of a joint partnership with a vendor. The reward to any vendor is the opportunity to develop its systems in a prototype of future educational environments. This provides both a test bed and a living example for marketing purposes. The rewards to CMU are a major sharing of the costs of computational expansion, together with less

tangible rewards such as direct impact on the evolution of the educational computer industry. While the details of any such joint partnership are far from determined, it clearly would involve a long term relationship with a large industrial computer firm. Though part of a developing pattern in the 80s of university-industry relationships, such a partnership contains some risk—as one would expect in an attempt to seize leadership. The Task Force believes such developments can be well worth the risk, although the details must be examined carefully.

• **Computation has some remarkable properties as a candidate for a leadership area.** CMU, as every university, seeks areas in which it can be excellent and provide leadership. Excellence in the various distinct scholarly areas are largely the separate achievement of each (although excellence in teaching in one area certainly requires good quality teaching throughout the university). In contrast, computation, although peripheral to the main tasks of the university, supports all other areas. It enters into some much more than others, and in separate ways in each, but it enters directly.

Leadership in the development of an outstanding computational environment can directly help other areas in their own search for leadership and excellence.

Thus all areas have a direct interest in the quality, diversity, and organization of the computational facilities. Leadership in the development of an outstanding computational environment can directly help other areas in their own search for leadership and excellence. Thus, development of outstanding computation has a unifying, synergistic influence on the university as a whole.

• **How to deal with the costs of leadership.** There are costs of leadership. First, there is intrinsic risk in exploring any new area. Thus, we should move cautiously and proceed in a way which maintains the greatest possible flexibility, and care should be taken to establish contingency plans to restrict this risk. Second, there are opportunity costs, for choosing to attempt leadership in one area means choosing not to attempt it in others. We believe there is no way out of some exacerbation of this problem in the present case. We would counsel a strategy of being sure the benefits of computing are truly widespread. We also believe that when a community chooses to place resources in one area, it accepts the obligation to be sensitive to the effects in other areas.[3]

The Report deliberately avoided specific recommendations on hardware. What eventuated, however, was a decision to go forward with the design and installation of a state-of-the-art system based on powerful workstations, enough for every member of the student body and professional staff, embedded in a sophisticated telecommunications network that would permit students and faculty both on and off campus to communicate with all facilities attached to the system. It included a storage capacity of 20-100 billion characters, or up to five times the amount presently in the CMU libraries. When the whole system is up and running, some 8,000 workstations will be needed. Beginning in 1986, entering freshmen will be required to buy the machines, paying for them in increments over their four years at CMU.[4]

Development and installation of such a system would be very expensive—many tens of millions of dollars. And there was another problem. Though CMU's computer science department had done research that could provide the basis for the design of the system, the amount of engineering required to go from the research base to a fully-configured system would be enormous. The solution was to find a commercial partner who would share the costs and rewards. Richard L. Van Horn, at that time Provost at CMU, tells the story:

> CMU probably could develop appropriate hardware and software, but the cost would be enormous—perhaps $50 million. Even more troublesome, an independent CMU development effort would have little benefit or impact on the broader community. History strongly suggests that the rest of the world hesitates, for good reasons, to adopt a university-created and -supported computing environment. Such environments tend to be poorly documented and poorly maintained. The most obvious solution to these

problems was to enter into a partnership with a major computer company.

In the summer of 1980, CMU began the search for a partner. Armed with a written proposal, a small group consisting of President Cyert, who is an enthusiastic advocate, myself, and, later, newly hired vice provost for computing, Douglas Van Houweling, personally presented the ideas to the top management of the companies. We asked for (a) funding for a software development center, (b) equipment and/or financial support to implement an advanced prototype environment at CMU, and (c) a commitment for a complementary development effort inside the company. Our proposal argued that the system and environment we described was the dominant model for the future of computing, not only for universities, but for most organizations. Therefore, the project held substantial economic significance for the company. In addition, CMU could offer an outstanding computer science department, a leading computing environment, a university of reasonable size and diversity for such an experiment, and a university-wide commitment.

Our proposals were received with great interest and strong reservations. Companies clearly were fascinated by the idea but expressed the obvious concerns. Is networked personal computing really the model for the future? If it is, can CMU contribute enough to justify the cost? Finally, is there a suitable arrangement that meets the mutual concerns of company and university? In retrospect, a critical factor was that our proposal had enough impact and credibility that corporate top management used it to generate discussions within the company. Those discussions quickly brought support from people within the company with similar ideas.

History strongly suggests that the rest of the world hesitates, for good reasons, to adopt a university-created and -supported computing environment.

Late in 1981, IBM decided to proceed by setting up a six-month joint feasibility study and dispatched a small team to live at CMU. The study concentrated mostly on technical feasibility, although it also examined marketing issues and contractual arrangements. During this period, IBM had time to form its own views and plans for networked distributed computing, and a large number of people inside IBM were exposed to the proposal. The joint study also resulted in key people at CMU forming strongly positive opinions of IBM, and it exposed the campus community to the possibility of a major joint project. The positive reactions on both sides that grew out of the joint study were a key precondition for the eventual contract.

By advocating a substantial increase in computation at CMU, we are advocating that CMU lead universities into a world saturated with computation.

The contract itself, at CMU's initiative, assigns all intellectual property rights to IBM. Some important policy issues are involved in this decision. Everyone agrees that the goal of universities is to create and disseminate knowledge for the benefit of society. The question, of course, is how to best achieve the goal. Many universities have argued that only by retaining patents and copyrights can they assure wide dissemination of ideas. We argue the exact opposite. Universities have compiled a dismal record of profiting from their own patents: most university-owned patents sit in a file unused until they quietly expire. The most effective way to bring about dissemination of ideas is to give ownership to a company with the resources and profit-motive to exploit the ideas. In short, we want to make it as easy and attractive as possible for a company to use the ideas.

Arguments against this approach are unconvincing. One can argue that universities are giving up valuable income, but few universities realize much income from patents. In addition, universities can give up ownership and still negotiate to retain a share of the revenues, if any. A more significant argument is that by giving up ownership, the university may open the opportunity for the company to withhold or suppress the idea. However, if the idea is valuable, why should a company with-

hold it? In any event, since patents and copyrights are public, the ideas also are public. If the idea has merit, someone will find a way around the patent.

The IBM contract, like all CMU contracts, gives faculty and staff members the right to publish ideas from the research. In assuring the free flow of ideas, publication is a much more valuable right than patent ownership. The contract does provide for limited delay of publication to give IBM the opportunity to protect its intellectual property rights. Furthermore, the IBM contract does not in any way restrict CMU's ability to work for or contract with other sponsors, including competitors—another valuable right.

In assuring the free flow of ideas, publication is a much more valuable right than patent ownership.

Although generalizations should be made with care, the CMU-IBM agreement does suggest a checklist for industry-university relationships.

1. Build on strength. CMU offered a history of excellence in computing and an outstanding computer science department. IBM probably would not have entered an agreement without these strengths. Internal funds, government, and foundations remain the most likely sources of support for building initial strength in an area. In the IBM case, the research is also highly applied in the sense that it may result in an IBM product line. A substantial amount of basic research may occur during the project, but the project in broad terms is applied research.

2. Offer a fair exchange. CMU did not ask IBM for a handout or appeal to IBM's charitable or civic duty. We came up with an exciting, innovative idea of at least potential value to IBM. We also asked for a sum of money that was large enough to catch the attention of top management. We were careful throughout the discussions to argue the value of the project to IBM and the value and uniqueness of CMU's contributions. We made a number of compromises to reach positions that IBM felt were important. To the best of our knowledge, no one else ever had made a similar proposal to IBM. Our conversations with senior IBM personnel suggest that our proposal and discussions had a significant impact on IBM thinking independent of the research yet to come. We suspect that it is this type of initial impact that leads to contracts.

3. Have a small, clearly defined set of goals and constraints. Before sitting down with IBM, we thought deeply about what we wanted and what we were willing to give up. Our enthusiastic release of intellectual property rights gave us a base on which to ask for what might seem a ridiculously high level of support. We tried to be reasonable about delay of publications without compromising our right to publish. We did not give IBM a standard CMU contract: we let IBM draft the initial agreement because they had many concerns and we had only a few, a decision that appeared to save a lot of conflict and time. We encouraged IBM to participate actively in setting policy and goals for the project and in reviewing performance. In turn, IBM gave us full operating control of the research and the staff. In short, by having a small, clear set of goals, we could readily agree to IBM's wishes on a large number of issues of modest concern to us, and we could fight hard for our position on a few critical issues. We did not get everything we wanted, but we did get an agreement of great interest and benefit to CMU.[6]

Brown University

This approach, clearly, is only open to a few universities, because the advantages to be gained by the firms involved can be gained with a handful of partners. Not long after the CMU/IBM announcement was made, Brown University, which had long had a close relationship with the Watson family and IBM, realized that the "window" in time available for concluding a similar relationship with IBM would be very small. Though not a technical school like CMU, Brown had characteristics that made it very appealing to leading computer companies as a potential partner: it was a leading liberal arts institution and an ideal place to show that computers could be used to advantage outside the context of mathematics, the hard sciences, and engineering; it already had put in place the most extensive and up-to-date campus telecommunications network in American higher education; its computer science department, though relatively new, was first rate; and it had already undertaken some very interesting experiments in the application of computing to instruction.

But why would Brown be interested in making a very large investment in information technology? Like CMU, Brown was faced with an exploding demand for computer services, and, like CMU, Brown believed that this demand could not be adequately met by simply expanding mainframe computing. After assessing the situation, Brown concluded, like CMU, not only that advanced information technology could greatly enhance scholarly activity in virtually every domain, but also that the rewards for leadership in applying that technology to scholarship would be great.

So, Brown has now launched a ten-year program to design and install 10,000 "scholars' workstations" in their campus communications system at an estimated cost of $50-$70 million. There will be enough workstations to serve all students when the development program is complete, but Brown has not yet decided to make student purchase of computers mandatory. Two equipment grants, one from Apollo Computers for $600,000, and one from Apple Computer for $500,000 have been secured. But the major source of support is again IBM, with which Brown is entering into a partnership with a dollar value to Brown of about $15,000,000 over three years, making it the largest single corporate partnership in Brown's history. The relationship involves both a grant and a joint venture.

The sense of excitement on the Brown campus is nicely captured in an article in the Brown Alumni Monthly:

> "We are looking at a massive change in intellectual society," says Andries van Dam, chairman of the computer science department and one of the architects of the proposal. "If you aren't scared about the implications of this change, how it's going to revolutionize teaching and research, you're not thinking."

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The University community has had several months to think about the computer proposal and how it is going to affect the quality of education and the quality of life at Brown. Many of the questions that are being raised have no answers—and won't for years, even generations—and as van Dam says, "We don't even know what most of the questions are."

"It's 1905 and you have seen your first horseless carriage drive down the street" he offers as analogy. "Your job is to plan the impact of this machine on the American economy, society, infrastructure. Think about what people must have felt like, the predictions they must have made. We're not the inventors of the new computer technology, but we're among the first wave of ardent enthusiasts. I feel we don't know anything about the impact at this point."

Perhaps the first question is, Why now? What is it that makes the time ripe to attempt an experiment of this scale and nature?

"It's a question of what's happening in the world out there," explains van Dam. "There is a growing awareness among computer manufacturers that workstations are the wave of the future." The scholar's workstation is a package of computing tools that lies at the heart of the project. In the

beginning, the workstations will provide secretarial functions, but soon, as libraries and other databases become accessible to computers, the workstations could be used more like research assistants. "We've been working longer on the workstation than most schools. We have a track record in using them, not just research on them. We're the only ones with a teaching lab like the Gould Lab, and we've been pioneers in the graphics area, which is an important part of what workstations are all about. No one else has even a year's worth of experience using workstations in the classroom setting, and although we have only a year's worth—which is minimal—it's the old story that in the land of the blind, the one-eyed is king. We are the one-eyed in this land-of-blind use of workstations in the classroom."

"The workstations will provide secretarial functions, but soon, as libraries and other databases become accessible to computers, the workstations could be used more like research assistants."

William Shipp, associate provost for computing, says, "There is a belief among zealots that this is going to happen no matter what we do. If you accept that fact and realize that it has the potential for major social change—both positive and negative—and if you realize that many schools with different goals may be shaping the technology, you come to the conclusion that *we* have the opportunity to shape the new technology, too, and to do it in a way that's really appropriate to Brown."

Another reason to face the computer issue now is that the demand for computing on campus is growing at a phenomenal rate. "Last year the growth rate for research and administration needs was 80 percent," Shipp says. And students were camping out in the computer science department for days hoping to sign up for CS 11—introductory programming. "If we think about how we can meet the growing demands while coping with the dissatisfaction with the style of computing we have now, we know we have a dilemma. Then if we know there is something that has greater promise coming down the road, it makes sense to seize the opportunity."

The question that has fascinated van Dam since the mid-1960s is "What do scholars do? What do they want computers for beyond word-processing functions? We will now have what the propaganda has been promising: computers as intellectual helpmates."

The computer will lessen what van Dam calls the "dog work" of research: the physical hunting through libraries for books, the re-typing of bibliographies, rewriting drafts. And for specialized fields—mathematics, engineering, classical languages, Egyptology—where symbols other than the standard alphabet are used, advanced graphics can provide on-line source materials. If the basic drudge work is alleviated, the possibility for increased productivity emerges—for better or worse.

"There is a danger in scholarship of people producing too much," says Roger Henkle, chairman of the English department. "There is already too much produced in my field [the nineteenth-century novel], but it's true all through the profession that there are people who haven't carefully edited or thought through what they want to say. With the ability to store and manipulate a lot of material, the computer can produce scholarship that is basically a collection of data. Because you can absorb and manipulate material more readily, in some cases there is a temptation to produce."

Henkle, who does intend to use the computer, says he has resisted it thus far because he didn't want to take the time to learn it and didn't feel it would save that much time with his research. He has also resisted for "semi-philosophical" reasons, and voices a concern heard frequently among humanities scholars. "People in my profession revere the book, and the computer signifies a kind of alienation from the book. The book itself is an object of crucial importance. The way you handle it, the way you deal with a book is different from how you deal with computer material . . . that sense of reading backwards and forwards, browsing through it. One of the things that we have to talk about when we consider the great advantages of the computer for research is that one of the ways people end up discovering things is by browsing through the stacks, and that won't be possible, no matter how many books are catalogued on the computer. The sense of the book as an artifact that carries a great deal of prestige and the tradition behind the book are something the computer won't propagate."

Merrily Taylor, who like Henkle served as a consultant on the original proposal, says "we want

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to make sure we keep the virtues of the older systems while approaching and moving into the new world. It's important that people realize it's not a tradeoff of technology for tradition. I don't think it's practicable or desirable to put *War and Peace* on a computer or to read it on a CRT, but maybe you could do a lot of exciting things with manipulating the novel to discover why Tolstoy used a particular verb far more than any other, for instance. But there are still going to be lots of situations where the plain old book is going to be the best way to store certain kinds of information.

"If the university has a basic commodity that it both trades in and lives off, it's information," she continues. "You can't conceive of a place like Brown without its library. If the library was gone, would you still have a university? We're a fundamental resource." It's a resource that, with computerization, may no longer be free, which raises provocative questions. "If people are going to continue to do research and pass it on to students, they have to have access to the information and they have to have it in a way that is more or less democratic. You can't say to certain segments of the University, 'You have access, but you don't.'

"Let me give you an example. It used to be that a library would buy something like *Chemical Abstracts* and pay $2,500 a year for the subscription and it would be available in the reference room. If you wanted to use it, you would walk in and use it—even if you used it ten times a day there was no cost to you. Now if you want to use *Chem Abstracts* on-line, there is a connect dialing charge, a citation charge, a charge for printing out your citations. Someone has to pay for that. Right now, the library is, but as more reference materials are put on-line and become available in that form, we will have to look at the whole philosophical issue. A lot of this information is now being provided by the profit sector—they are doing it for money, it's not in the hand of higher education or the non-profit sector. What does that really mean when we start looking at an information society where there will be haves and have-nots depending on whether you can pay for the information you need?"

Taylor adds that one of the exciting aspects of the computer experiment is the prospect that Brown and other universities might be able to cooperate on acquiring data bases of their own and mount them on university computers. "This would make the information accessible to people in the university community without any of the charges."

"We in the humanities are, and will continue to be, very library-reliant," says art professor Kermit Champa. "The technical disciplines work for the most part with current periodical literature, which goes on-line very easily. But those of us who work with out-of-print antiquarian documentary materials are working with materials that will probably never be able to be transferred because of the man-hours necessary to do so."

Another practical concern relating to time is voiced by Marc Parmentier, associate professor of geological sciences. "How are faculty members going to be able to take the time to develop the programs they will be using in their classes? If we are supposed to do that in the summer, when will we have time to do our research? There may be a degradation in the quality of teaching in the short term, and research in the long term."

The scholar's workstation is, in van Dam's words, "a teaching tool of unrivalled dimensions. It's like having the best of television, transparancy projectors, and chalkboards; but it's much more malleable than any of those, and the student can control it." Not only will the workstation be flexible, it will be amazingly powerful: "Each of the new Apollos in the Gould Lab is more powerful than the central time-sharing computer that we had in the computing lab for the entire University in the mid-60s."

"The sense of the book as an artifact that carries a great deal of prestige and the tradition behind the book are something the computer won't propagate."

Admittedly a zealot, van Dam believes the possibilities of using the computer as an enhancement for traditional means of teaching are endlessly exciting. He points to the poetry project sponsored by the National Endowment for the Humanities that he "spawned at Brown in 1975." This experiment made use of "hypertext," networks of cross-referenced, linked manuscripts with their associated marginal notes, key-worded passages, exchanges with other students, and other references. A student could look at the screen and see the original poem as well as comments made by the professor and fellow classmates. "One of the things I was just charmed by in the NEH poetry experiment,"

says van Dam, "was that people were working much *more* together because of the electronic medium. They were writing to each other, marking up the text, then someone else would read the comments and write comments on the comments. There were whole dialogues going on; it was neat, really fun." In addition to the increased inter-communication, students who were working on the computer wrote three times as much as did those in two control sections of the course, with no decrease in quality. "People admitted that they really got into it and it was *miserably* inconvenient. You had to sign up for your hours and hope that the machine was up. It's not like sitting at your workstations at two in the morning and when you get an inspiration, you can quickly bang something out."

Henkle is "interested in using the computer in my journalistic writing class. Most of what we're doing involves rhetoric emphasis, moving things around, handling material, rearranging your examples; and it seems to me the computer will be particularly useful for that purpose." He thinks, though, that until every student is equipped with his own computer, there may be problems teaching writing on the computer.

Mary Lewis, an associate professor of music, has been doing her research with the help of computers for years, and she says that "to say I am enthusiastic about this project is to put it mildly. Hypertext is one of the most exciting concepts to come along . . . that and the increased communications capabilities of computers are really valuable.

"One thing we'd like to see in my field is the development of a music editor, which could edit music the way you do text. It seems to me easy to integrate graphics and text. Once we can run music [through a computer] the way you do words, the next step would be the development of a music skills laboratory, where we could use the workstations to develop music skills—composition skills, harmony, music reading; all the fundamental skills of musical literacy that go beyond theory.

"If a keyboard could be developed like a piano keyboard, where you could play and the notes would be typed right in, students could upgrade their skills, work in a self-paced way, and make the work go much faster. It would also free up the faculty to teach more creatively."

Lewis says that the computer will make music composition essentially a whole new field. "Just copying out scores is expensive and time-consuming. It could take so much of the drudgery out of it if you could do it on computer. I've seen programs where you can hit a button and the entire score can go up or down a fifth. As people use these machines, and become aware of the potential, they will change our work habits. The ease and speed of learning on these workstations is amazing."

"It's conceivable that the computer could create a kind of atmosphere where the seminar workshop situation is diminished," offers Henkle. "One of the most important things we teach in college is the ability to articulate in a group of people where there is dialogue, confrontation, interrogation. You have to have the poise to handle yourself verbally, and the need for that is not going to go away no matter how many computers you have. Conceivably, it's going to be very easy for the shy person to avoid those situations if he can." But Lewis thinks that "people who have trouble interacting anyway will get into using [and abusing] the computer. It will increase communication rather than decrease it."

Van Dam says, "I don't want classes to disappear, I want them to continue. I just want another mode. I don't want to be forced to choose. I know perfectly well that the classroom can be an artificial setting. For a small percentage of people who are articulate, like to show off, or are genuinely unafraid and enjoy the dialogue, it's a good setting. So what do we do? We try to break it down into discussion groups, smaller sections—but these devices are just devices. I'm suggesting that we add another kind of section, the electronic section, where a person can work to overcome the shyness or the fear of communicating. I'm for creating additional avenues, not eliminating them. I now have infinitely more student contact than before. I am pretty difficult to get hold of, but if you send me an electronic message, I will receive it when I log on. When I finally answer my mail it could be two in the morning, but I answer my mail." (As if to demonstrate van Dam's point, his computer terminal beeped several times in the

The announcement that $50 million was going to be spent over the next six years to equip everyone on campus with workstations was greeted with surprise and concern.

course of a couple of hours—students and colleagues sending him electronic messages).

Mary Lewis agrees. "I've had students say, 'I tried to reach you for so long,' when they needed help. If that student could reach me through electronic mail, we wouldn't miss each other. The computer reduces the physical gaps this way."

The announcement that $50 million was going to be spent over the next six years to equip everyone on campus with workstations was greeted with surprise and concern. The administration firmly stressed that this money will be raised from sources other than current operating expenses, and that fund-raising for all other needs will continue.

("There are times when money is available for some things and not for others," explains Shipp. "There isn't any real answer to that. As a University we have to take advantage of the opportunities." Shipp points to the rapidity of fund-raising for the experiment so far: "We've never had a period where in January a group of people started a fund-raising activity and three to four months later there was $15 million in the coffers.")

Among those expressing concern is John Savage, a professor of computer science, who asks, "How do you balance the risk against the opportunity?" A computer scientist who believes the computer is not a panacea, Savage already has access to tools that are more powerful than what will be generally available to the Brown community. "I know what to expect. I'm also aware of work being done in other universities, and I think I have a fairly honest assessment of the potential out there.

"Let me say that this project has the potential to transform the University, hopefully in ways acceptable to all. But it comes at a time when we are pulling out of what most people consider a financial crisis. We are only marginally solvent. We have one building that hasn't been paid for [the geo-chem building], we haven't brought faculty salaries to a level people would find generous, and our library needs a vast infusion of capital. We have had faculty pleading for years to increase the [library] acquisition budget. I know there are faculty on campus housed under inferior conditions. Other faculty members will point to the woefully inadequate classroom situation that needs to be dealt with; students will say why the financial-aid budget is still lacking. The president is taking a hard position about not putting up internal money for this project," Savage continues. "He can't hold that line indefinitely, simply because for campus computerization to work, it means computers must be in *every* office. You need a lot of central and distributed resources, and those have to be paid for by somebody. If a faculty member receives a workstation for research, there is no question that he or she will see its potential for teaching. There will then be a demand created for that. The Institute for Research in Information and Scholarship [see below] will bring in machines, but I don't believe they see it as their mission to fund all the computerization that's going to take place on campus. Instead they will expect departments and administrative offices to raise their own funds. At that point you can't hold the line anymore. You have to pay for these resources out of existing funds."

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What Savage has articulated is what van Dam calls the "camel's nose problem. It's an ancient Arab proverb. Once the camel gets his nose into the tent, the rest of the camel will follow soon. I know what we can't say is, 'Let's put 10,000 workstations all over Brown and by eliminating financial aid, the library, salary raises, let's kill off the University.' We may have won the battle, but we would have lost the war. We are keenly aware that we have to do this primarily with monies we've raised. That's the key issue. But how can we raise those monies? Not by being number five. You have to be number one, you have to be a pioneer. You have to make people willing to invest in you because they think you may conceivably lead to some questions and answers that *matter*. The money will come if we do good work. Not all of it, there will be some hardships, there will be some reallocations. But it's not something someone is going to decide in lonely splendor. It will be argued fiercely up and down the corridors of power, with all the input and insights of whatever committee is looking at it."

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One of the things that makes the Brown experiment different from other projects is the Institute for Research in Information and Scholarship (IRIS), established with support from IBM.

tute for Research in Information and Scholarship (IRIS), established with support from IBM. "The Institute is really the cornerstone of Brown's entire project," President Howard Swearer said when he announced the establishment of the institute. "From IRIS will stem the technical and creative impulses that will drive and focus a broad range of experiments. Information developed by IRIS will show us how the next generation of computing can best serve faculty and students in the humanities as well as in the sciences, preserving our strong liberal arts tradition."

Shipp has been appointed director of the IRIS, and he explains that "there will be an executive committee composed of faculty and staff who will function like a corporate executive committee. This group will be intimately involved in recommending policies, in looking at the directions of the institute's activities." Another committee, made up of project leaders, will be the management committee; another will be responsible for implications and evaluations, and will be looking at social and psychological impacts of the project as well as evaluating education, scholarship, and social changes. Yet another committee will be responsible for training and deployment. "The whole training issue is crucial. In January 1984 there may be hundreds of students with machines that they have bought. Within the next year there could be thousands of these machines on campus, and it's going to be a major effort to provide a whole new kind of training to faculty, staff, and students. One of the biggest problems we saw in talking to the departments is lack of training. We don't have any training facilities for faculty and staff. We're actually sending people to Johnson and Wales College to take courses about computing, which is insane."

The question of "who gets what, when" is, according to Shipp, a complicated one that won't be entirely up to IRIS to determine. "There are certain considerations that have to be made primarily on a technical basis," he explains. "For instance, in 1984-85, the workstations have to be used primarily to set up two workstation labs. Those will not be generally available terminal centers, but will be available for courses that use them. So there's a decision that will be made first of all to meet the requirements of the experiment going on and the development process. We will be requesting applications for uses for the Lisas we have received. The initial hundred IBM PC's are more or less targeted at the biological or physical sciences, while the Lisas are more or less for the arts and social sciences. That has to do partly with the wishes of the manufacturer, and it's a general strategy. The whole name of the game is workstation networks. We want to establish smaller workstation networks within the departments. There will have to be some group formed that will decide and evaluate the proposals for the machines. This is not just a computer science or engineering project. This is a University project. We are trying to distribute the most appropriate technology to the groups on campus that can best benefit. It will be a complicated process."

The industry tie-in is something that raises other intriguing questions. Joan Richards, an assistant professor of history who served on an ad hoc subcommittee of the Faculty Policy Group set up to study the project over the summer, says that one of the committee's concerns is the copyright problems of the software that faculty members will be helping to develop: Who will get the money? Mary Lewis adds, "We in the academic world have been living in a state of innocence. We haven't dealt with the secrecy and the potential for profit that goes on in the business world. The possibilities for us to make money developing the software is looming ahead and we have to start thinking about that. People in the humanities aren't used to being in that position."

"We have to pay attention as best we can to the unanticipated consequences," says Edward Beiser, professor of political science and director of the Center for Law and Liberal Education. "What is an example of an unanticipated consequence? Question: What are the implications of this program for admission decisions at Brown? If we have the potential to give every student at Brown a terminal, should we not when we admit a class try to attract and recruit students who have the capacity to use that terminal? You don't invest in this kind of hardware and then remain indifferent as to whether and how it will be utilized. By way of analogy, if we accepted the donation of a new language laboratory, so that there was a seat in the lab for every student at Brown, that would make no sense unless lots and lots of students were going to study foreign languages."

Will the project change the kind of student attracted to Brown? Two replies. Dean of the College Harriet Sheridan: "I think if we weren't to do it, it might. The liveliest, most enterprising students that we see at Brown struggling to get into CS 11 are coming from all fields. Why shouldn't humanists know about machines? The problem with humanists in the past has been that they

haven't wanted to recognize their dependence on machines. Yet they drive cars, use refrigerators and stereos. I would say were we not to do this, we would lose many of the students that we want." Music professor Mary Lewis: "I asked one of my students—one of those who is most wonderful—if he would have come to Brown with these computers. He said he wouldn't, but that students coming in now wouldn't be bothered in the least by this experiment. That's how fast things have changed."

"This institution is special," says Savage. "It has been for a long time a friendly, homey, easy-going place, but we have been experiencing a diminishing sense of community. I would want to know what's causing the change. What disturbs me is that there is no dialogue. We're introducing technology instead of giving attention to the problems people have."

"Are we as a University discussing education enough so that we are ready to discuss this kind of education in conjunction with everything else?" Beiser inquires. "If every professor has a terminal in his office, and terminals are accessible to every student, we will then have a discussion of whether we should have a computer requirement at Brown. But we don't now have real discussions about whether we should have a writing requirement or what that might mean. Or a reading requirement and what that might mean. What is the educational framework within which we will discuss the place of the computer at Brown? The computer issue forces us to interact on some educational issues."

"Brown is attempting to humanize a technological trend," as Lewis puts it. "We have to find ways to use the things creatively. We live in a technological society and we can't run from it."

According to Shipp, "Very little has actually happened yet. The perception is that 'they' have gone so far that all of the decisions have been made. What we've been trying to do is create a set of opportunities. What has complicated things is the success of the fund-raising. If it had taken us ten years to raise the initial money, people would have forgotten all about it."

People have not forgotten. The computers are coming and the debate is here. And Brown, ten years from now, will be a vastly different University.[6]

M.I.T.

The last of the 'star wars' universities to announce its project was the Massachusetts Institute of Technology. Andy van Dam of Brown remarked to me that it is noteworthy that Brown, a liberal arts institution, styled its project "The Wired University," whereas M.I.T., a technical institute, drew on Greek literature and mythology to name its venture "Project Athena," a description of which follows:

> On May 27, 1983, the Institute announced to the M.I.T. community and the general public the birth of Project Athena, a major Institute-wide experiment on the integration of modern computer and communications capabilities into all phases of the educational process. Athena's principal goal is to help our students learn more creatively and fully in a wide range of disciplines. We hope to use powerful computational and graphics resources to help develop new conceptual and intuitive understanding and to improve and refine our teaching methods.
>
> Athena is based on the hypothesis that the imaginative use of an interlinked network of computer workstations can greatly enhance the quality and effectiveness of our educational program. Given the opportunity and the means, we believe that M.I.T. faculty, working with students and with the help of support staff, can develop software tools that will significantly improve the ways in which students learn concepts, develop intuition, and expand their creative abilities. We are, if you will, bringing our newest technology to bear on our oldest aspiration—the education of our students.
>
> Over the years there have been many discussions at M.I.T. concerning the need for a major infusion of computing equipment specifically for educational purposes. The 1979 Dertouzos/Burner Report, *Ad Hoc Committee on Future Computational Needs and Resources,* for example, recommended networking the entire campus and distributing several thousand personal computers by 1989. Little advance was made toward these goals, though, until a very special "window of opportunity" opened in this past year, which prompted the initiation of intense discussions between M.I.T. and computer manufacturers.
>
> In the fall of 1982 the long-range planning efforts of the School of Engineering identified educational computing resources for undergraduates as a principal objective in each of the departments.

At the same time several major changes were occurring in the technology of personal computers: (1) the development of 32-bit microprocessors promised personal computers with capabilities approaching those of today's large minicomputers and medium-sized mainframes; (2) advances in network technologies made it feasible to consider linking together several thousand workstations; and (3) manufacturers began to realize the importance of the educational market and the value of creating a large body of sophisticated software expressly for that market. Hence there appeared a convergence between the needs of M.I.T. and those of the computer manufacturers. This convergence could not have occurred much earlier in time and is not likely to occur at the same level of interest again in this decade.

Discussions between the School of Engineering and major manufacturers began late in 1982 and were expanded to include the other Schools in early 1983. As negotiations progressed, it became clear that there were several advantages to be derived from involving more than one manufacturer in the project: flexibility for future developments, linkage to more than one approach to emerging computer technologies, and the creation of a more realistic multivendor environment in the Athena network, which would increase the probability that the project's results could be readily transported to other universities.

Several committees are already at work putting Athena into action. All parts of the Institute are represented on these committees, which will oversee the implementation of the project and the allocation of its resources. Now that Athena has "gone public" to the Institute, our immediate major goal will be to increase understanding of and involvement in the project and to initiate the process of soliciting concrete proposals for use of the new resources.

Athena's principal goal is to help our students learn more creatively and fully in a wide range of disciplines.

We believe that computers can be used beyond mere calculation to create environments that enhance exploration, experimentation, and, therefore, learning. We foresee, for example, the development of interactive modes of instruction based around a teaching facility with workstations available to each student and to the instructor. Such a system could be used in a number of ways:

- Students follow at their workstations what is being done at the instructor's workstation. If they wish, they can capture the material presented by the instructor in their files for further review,

We are, if you will, bringing our newest technology to bear on our oldest aspiration—the education of our students.

reference, and development. An instructor might use this mode, for example, to compare DNA sequences spanning an eon of evolution or to illustrate the perturbations of crystalline structures under a variety of conditions.

- After observing an instructor's work, students use that work, perhaps with modifications and extensions, to deal with new situations. An instructor might create a model bridge design, for example, and students would then modify the design to test the effect of different traffic load conditions.

- Students work on their own at computer-based exercises, with instructors and teaching assistants available for tutorial assistance. After performing a chemistry experiment, for example, students might use the computer to simulate a wide range of related experiments or to compile and analyze the results of their own and other students' experiments.

- Instructors employ programs designed to simulate the behavior of complex organizations and systems to illustrate real-world economic and political situations. This allows the introduction of models more complex than those normally used in the classroom and in problem sets to exemplify concepts. After suitable orientation, students might use such a system to follow out and compare the consequences of difficult policy alternatives.

Outside the classroom, students might try experiments of their own or pose "what if" questions to check and refine their understanding of basic concepts. The educational significance of providing carefully selected environments in which stu-

dents can explore in this way is supported by a substantial body of theory and experience.

We also envision that student-faculty groups working with an appropriate set of computer tools could evolve into a new type of community of scholars, sharing work and exploring ideas in ways that would not be possible in lectures, recitation sections, or seminars. New forms of mediated dialogue within the group become possible, permitting class discussions, lectures, and other forms of personal contact to assume a more dynamic and intensive character.

The teaching of design—an important focus of many M.I.T. programs—should be a prime beneficiary of the ability to create interactive environments in which designs can be quickly realized, exchanged, and critiqued by peers and teachers. The sophisticated workstations of Athena will allow architecture students, for example, to create three-dimensional models of buildings that can be viewed from any perspective and can also be modified at will.

Finally, looking well ahead and extrapolating from current computer science research, it may eventually be possible to create systems that tutor students directly and assist them in solving problems. As the student develops a step-by-step solution to a problem, the computer constructs a network relating the steps to each other. In addition, it has been taught to recognize the most common errors students make in such problems. Given this knowledge and the ability to perform mathematical manipulations, the computer prompts the student whenever he or she makes a mistake in either formulating the problem or carrying out the associated mathematics.

We foresee, for example, the development of interactive modes of instruction based around a teaching facility with workstations available to each student and to the instructor.

These are only a few examples of "new ways to learn." If Athena is a success, we shall discover along the way many more innovative ways to employ computers effectively in the educational process, even as we improve our understanding of how computers affect the learning environment. These innovations will spring from the creative talents of our faculty and students.

The goal of Project Athena is to create an environment that is conducive to exploring the educational applications of computers and that capitalizes on the unique capabilities of M.I.T.'s students and faculty. In assessing the needs of the Institute during the initial formulation of Project Athena it was decided that this goal would require the following additional resources:

- Access to a reasonably large number of fairly powerful computers with adequate memory and file storage.
- Access to an adequate number of graphics systems with versatile support software.
- Support for faculty and student time to concentrate on the development of new learning tools.
- A versatile underlying software system that is reliable, well maintained and documented, and common to the entire community.
- Opportunities to learn new programming languages and related techniques.
- Opportunities to share and accumulate software resources in an efficient manner.
- Opportunities to experiment with new software tools in the learning environment.
- A forum for exchanging ideas related to the use of computers in the teaching/learning process.

With these general goals in mind, then, M.I.T. approached several computer manufacturers seeking their participation in and support of the project. It soon became clear that two major manufacturers, Digital Equipment Corporation and IBM Corporation, were most interested in the educational goals of Athena as well as the associated technical issue of coherence.

We saw clear benefits to working with more than one manufacturer. Such an arrangement would allow us to test the use of our software tools on a variety of equipment and to benefit from the expertise, knowledge, and future plans of more than one industry leader. It would also help to ensure that the new educational tools developed here could eventually be readily shared with colleagues at other universities.

We therefore sought the support of *both* Digital and IBM in this project. Staff from both companies would be working with us on a full-time basis to create new educational software and a large network of interconnected personal computers, and to develop ideas for future products that

might increase the usefulness of computers in the educational process. The effectiveness of Athena's educational experiments will be considerably enhanced, and the chances for cross-fertilization increased, if the project takes place on a relatively uniform system base that is independent of underlying hardware differences and that facilitates the sharing of data and programs throughout our community. We have chosen to designate these desirable unifying properties of the Athena system by the name *coherence*. Coherence is achieved when two imperatives are met:

- The system should be as hardware-independent as possible. That is, users of various computers should see the same programming languages, software tools, and subsystem environments for program development and intercommunication purposes.

- The system should facilitate the uniform sharing of data and programs among users who wish to share their work. Thus, for example, data collected by one user should be easily available to another user's program; and a program developed by one part of the Institute should be easily available for use as a component of programs being developed by other members of our community.

The goal of coherence is to render the differences in manufacturers' equipment transparent to the user community. Nevertheless the need to protect the proprietary knowledge of the two companies led us to decide on a separation between the domains of application of the manufacturers' products in the early stages of the program. We also concluded that unannounced products from the two companies should not be used in the project.

As a result, it is planned that IBM equipment and support will be centered in the Schools of Architecture and Planning, Humanities and Social Science, Science, and Management, in Whitaker College, and in those activities associated with the freshman year. Digital equipment and support will be centered in the School of Engineering. Digital has made a commitment to the project for five years, and IBM for three years. M.I.T.'s activities related to the installation and location of equipment, the assignment of support staff, and coherence will be coordinated by committees that will include representatives from both Digital and IBM. This arrangement is satisfactory to the two companies, and their cooperation, support, and enthusiastic anticipation of participating with M.I.T. in the development of new methods for teaching and learning have been clearly evident.

The two manufacturers have committed nearly $50 million in equipment, staff, maintenance, and other support to Project Athena. It is a tribute to their broadminded support of our educational goals that they have both agreed to the following flexible M.I.T. commitments:

- M.I.T. faculty will work with this equipment to explore the use of computers as learning tools, and Digital and IBM staff will participate in these explorations to observe at first hand the nature of the tools developed and their effect on the education of our students.

- Digital and IBM will use their participation in the project to gain experience in the development and use of software and hardware for interconnecting a large number of personal computers.

- One of the goals of Project Athena will be to formulate appropriate approaches to the protection of intellectual property rights and the licensing and distribution of software arising from the widespread use of personal computers in a university setting. Digital, IBM, and M.I.T. are all committed to the use of applications software in an open academic environment.

In order to meet the financial requirement for faculty, staff, and student support, we have begun with the approval of the M.I.T. Administration a campaign to raise $20 million for support of Project Athena over the next five years. To date, approximately one-fourth of these funds have been pledged by individual and corporate donors.[7]

If Athena is a success, we shall discover along the way many more innovative ways to employ computers effectively in the educational process, even as we improve our understanding of how computers affect the learning environment.

At this point, the description of Project Athena turns to a discussion of technical characteristics of the workstations, operating systems, telecommunications networks, and so on. While the details may be of only peripheral interest for our purposes, some of what is said is to the point.

Unlike CMU and Brown, M.I.T. decided to go with hardware that is either currently available or now under development by DEC and IBM, concentrating their attention on the problem of "coherence" described above, rather than on development of new systems. Similarly, M.I.T. decided to standardize on the UNIX operating system and on just three high level languages for all their software development work: C, Fortran, and LISP. Taken together, the decisions to go with hardware, an operating system, and a limited set of programming languages, all of which are or shortly will be in wide use in American higher education, in combination with the decision to work hard on getting all these system elements to work easily in harness, should mean that those on other campuses will be able to benefit directly from the work done at M.I.T.

The goal of coherence is to render the differences in manufacturers' equipment transparent to the user community.

The description of Project Athena concludes with some comments about support services to be made available to faculty and students involved in the Project:

> In addition to hardware and software, Athena will provide support staff, funds to allow faculty time to work on software and coursework development, learning opportunities for faculty and staff, and support for student work on these projects.
>
> Support staff will help develop the general software tools needed by system users. In particular, they will be responsible for modifications to the operating system, installation and maintenance of approved software languages, modification of graphics software, provision of common application services, development of software network interfaces, and documentation and maintenance of these central software tools.
>
> During the five-year period of the experiment we anticipate a need for participation by 15 to 20 members of the M.I.T. technical staff, in addition to the technical staff supplied by Digital and IBM. These personnel will not only work on the development of the central system but also be available on a limited basis to provide software support to faculty and students developing learning tools.
>
> Support funds will be made available to allow faculty time to work intensively on individual projects. In some cases this support will be provided by the faculty member's department as part of continuing subject development efforts. In cases where the development of learning tools deriving from the project are consistent with the goals of ongoing research projects, support will come from existing research funds. In most instances, though, faculty support must be provided from new sources of funds developed especially for Project Athena. It is expected that about $12 million of such special funds will be allocated to curriculum development over the five years of the project.
>
> While some of our faculty have already begun to explore the use of computers in teaching activities, many others are still unfamiliar with their educational possibilities. It is clear that if Athena is going to be a success throughout the various disciplines of the Institute, considerable effort must be expended to give interested faculty the opportunity to learn, to experiment, and to exchange ideas with others who are involved in developing new approaches to teaching.
>
> Efforts are already under way to provide opportunities for faculty to learn more about computers and to develop higher-level programming skills. For example, special concentrated versions of 6.001 were offered to faculty both during IAP in January 1983 and during the summer of 1983. Approximately 70 faculty members participated.

. . . The decisions to go with hardware, an operating system, and a limited set of programming languages . . . in combination with the decision to work hard on getting all these system elements to work easily in harness, should mean that those on other campuses will be able to benefit directly from the work done at M.I.T.

We hope to put major emphasis during IAP 1984 on learning opportunities for faculty in subjects such as computing, UNIX, and the uses of computer graphics. We are also contemplating the possibility of offering 6.001 to faculty on a tutored video instruction (TVI) basis. As the project develops and the need for other skills becomes clear, we plan to provide as many learning opportunities as possible.

Opportunities simply to explore and to experiment with computers are essential, and Athena will provide access to the system even in the absence of a specifically funded project. There will be limited access in the 1983-84 Academic Year, with widespread access available by the 1984-85 Academic Year.

Finally, while a firm schedule has not yet been set, it is intended that Project Athena will sponsor a series of seminars at which faculty can share experiences with colleagues from both M.I.T. and other universities, so that the results of the various individual projects can be widely shared and built upon.

Of the funds being raised to support Project Athena, approximately $12 million will be allocated in support of curriculum development activities during the five years of the project. Given the significant scale of this funding, it is obviously important that the process by which funds are granted to the faculty be fair and efficient, and that funds be targeted to produce significant new results in the application of computers to the educational context. A balance must be sought between highly speculative projects with high risk and high potential payoff and more straightforward projects with immediate and more certain benefits. The desire for minimal reporting and administration must also be balanced against the need to ensure that reasonable progress is made. Finally, the desire to spread the benefits of Athena across the Institute must be balanced against the possibility that a few departments may, at least in the short term, be better prepared to use Athena's hardware effectively.

Support funds will be made available to allow faculty time to work intensively on individual projects.

In addition to receiving proposals from individuals and groups of faculty, the Resource Allocation committees may initiate projects on their own. For example, in cases where there are key areas of interest to many departments, one of the committees might bring together a group of faculty and encourage them to develop a particular type of educational software with broad utility. The committees might also encourage faculty who submit similar proposals to work together and might make funding conditional on such cooperation.

Of the funds being raised to support Project Athena, approximately $12 million will be allocated in support of curriculum development activities during the five years of the project.

The review process will recognize the fact that some projects will inherently carry a substantial risk of failure and that the goals of others may change as work progresses. This is normal in any innovative enterprise. Faculty should not feel discouraged from submitting high-risk proposals by the thought that they might always be required to show some sort of tangible workable results.

Priority access to Project Athena workstations must be reserved for curriculum development activities funded under the project and for students taking subjects developed under the project's auspices.[8]

Commentary

What can we say about the likely consequences of these three projects for the institutions involved and for American higher education in general? There may be a clue in a statement from the prime movers of the project at Brown:

> Our long-range goal is to find new ways through which computers and information systems can enhance people's thinking and learning and help them in their daily knowledge work.
>
> The improvements we seek through interdisciplinary experimentation, using computer workstations and an electronic communications environment, are:
>
> • Integrated methods for creating, accessing, filtering, synthesizing, and manipulating information.
> • More efficient processes and tools for learning, teaching, research, and the routine daily tasks that often impede or take valuable time away from the above; and
> • Enhanced group interactions with more sharing of work and more joint exploration of ideas.
>
> Our objectives are to achieve these improvements and make them available to the entire University community. In striving toward these objectives, we will have to bring about substantial changes in the mechanics of education and scholarship and their associated delivery mechanisms. This can be done only through involvement of the entire University in the effort.
>
> If these objectives are realized, students will play a much more active role in the classroom than they do now. The classroom will be extended to the dormitory and even off campus. The new dynamic media for both education and scholarship—as well as the new ways for individuals to communicate and interact with one another—will fundamentally change the university as we know it. Our aim is to preserve parts of the past worth saving and augment them through new methods and approaches, thus achieving a balance between the old and the new that better meets human needs.[9]

The authors speak of ". . . substantial changes in the mechanics of education and scholarship and their associated delivery mechanisms . . ." and of extending the classroom ". . . off campus." They believe "the new dynamic media . . . will fundamentally change the university as we know it." This language could easily be dismissed as an excess of enthusiasm or, perhaps, academic hype. But, in my opinion, it would be unwise to do so.

In economist's language, these universities are "capitalizing" higher education, doing in their industry what countless other firms in other industries are doing—investing in information technology to improve the productivity of their staff (and, in this case, students). In the economy at large, the rewards for those who properly capitalize their product typically include improved quality and lower unit costs, which often result in a bigger market share and an improved profit and loss statement.

Clearly, there are many important differences between a college or university and for-profit organizations that make the parallel less than perfect. Yet, the business of a modern university is the production, storage, retrieval, and transfer of information. The demand for the product of such a business is increasing very rapidly, not just among students and the research community, but in business and industry. These institutions are introducing information handling technology on a very large scale to an information industry—higher education.

Consider what would happen if a large firm could gain access to a modern research university through digital communication links. It could have access to the university's economic models, accounting models, models of physical and chemical processes, simulations of the environment, demographic data, historical data, books and specialized research literature in the libraries, photographic slides in the laboratories and galleries, digitized maps, and, through computer conferencing and electronic mail, to the faculty and graduate students. Suppose computer-based classes on campus could be attended by anyone at the end of a communications link anywhere. Actually, because a large firm is more likely to have some of these facilities on its own computer, one might better have chosen a small firm that was eager to make up for the disadvantages of size.

Right now, most of those resources are virtually inaccessible unless one is physically on campus and willing to trudge around from place to place. But the developments described above will make it possible to provide those resources to any-

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one willing to pay for them, virtually instantaneously, and without moving from their chair, wherever that chair may be.

And those same developments will make it necessary for those who have the facilities to offer them to people and institutions off campus. Brown estimates that it will cost between $6 million and $10 million annually to operate the system they are now designing, about what it now costs for Brown's library. The most straightforward way to cover the increased costs is to spread them over a larger customer base. So the institution will have a strong incentive to think about what it has to offer in ways quite different from the past. And those outside the institution will have an equally strong incentive to avail themselves of those resources. In short, those responsible for higher education institutions will have to think again about what business they are in.

Instruction, however, will not only remain central to the mission, but is likely itself to be transformed. As we have seen, the students who participated in the Brown hypertext-based poetry-criticism course wrote much more than those who did not. The introductory computer science course as implemented on the Apollo computers not only teaches more than the traditionally taught course, but does so in half the time. At Carnegie-Mellon, Douglas Van Houweling, vice-provost for computing, speaks passionately about the low value we put on student time, and how the environment CMU is creating will increase the student's productivity. Given that the student body for American universities will inevitably age in the future, and will draw increasingly on people already in the workforce, student productivity will become a far more important issue than it ever has been in the past.

It is likely that participation in this great experiment will be limited to a relatively small number of institutions. The reason, I think, will have less to do with financial resources than institutional characteristics. Those that appear to me to have made the most progress have usually been distinguished by relatively small size, a deep-seated sense of community, a genuine respect among that community for the leadership of the institution, a strong priority placed on instruction, and the freedom to take substantial risks.

The steady movement over the decades to decentralize authority in higher education institutions has made it very difficult for them to respond to the kind of challenge and opportunity inherent in modern information technology. It is especially hard for large research institutions, even more so for public institutions, which typically lack the capacity for autonomous risk taking that many private institutions have preserved.

If this analysis has any merit, then we could expect over time to see a restructuring of American higher education. Those institutions that had managed to capitalize themselves in the manner I have described would be in a position to market their assets way beyond their own campuses and would prosper. Those that saw their mission as assembling resources to meet unique local and regional needs—like many of the most successful community colleges—would find a new and powerful set of resources on the horizon that would make these institutions even more attractive than they are now. But, at a time when the traditional college age population is declining, institutions that offered nothing particularly distinctive by way of curriculum, or who were either unwilling or unable to use information technology to increase the productivity of students and staff, might well be in real trouble.

Hence, it is of great importance, when planning for the acquisition of this technology, to give some thought to the effect it will have on the character, perhaps even the prospects for survival, of the institution. Among those in the deepest trouble are likely to be those who buy this technology without thinking these issues through, for they will have simply added to their costs, which may just put them at more of a disadvantage than those who have done nothing at all.

Instruction and the Computer

There is nothing obvious about how best to use the computer for instruction. For a long time, the phrase had two meanings to most people: teaching people how to use the computer to conduct quantitative research, and teaching the computer how to instruct people (computer-assisted instruction). You will note that little has been said about the latter thus far, which is mainly the result of my strong view that, at present, computer-assisted instruction is among the least promising approaches to the use of the computer in higher education. As for teaching people how to use the computer to do research, I believe, as you will see, that we have only just begun to scratch the surface of the possibilities.

By way of illustrating the subtleties of this subject, consider the possibilities of using standard word processing software in the teaching of English. I recently encountered one English professor who had managed, after considerable travail, to get time for her students on the college VAX 11-780 minicomputer so that they could do their writing assignments with word processing equipment. She said that it was now a lot easier for the students to complete their assignments than it had been. I asked her how her teaching had changed as a result of the use of this expensive hardware. She looked puzzled. She taught as she always had.

In my capacity as employer and supervisor, I do not hand out grades to my staff when they turn in writing assignments. Million dollar budgets often turn on the quality of their writing. If their first try does not do the trick, I tell them what is wrong and send them back for a rewrite. Sometimes many rewrites. If the deadline is at hand, and it is still not good enough, I will rewrite it myself. If that happens, the writer from whom the task was taken is in trouble.

Some teachers at all levels of the educational system seem to think that their job is to sort people out by producing a bell-curve distribution of grades for their classes, when actually the job is to help every student do the very best they can. In this particular case, computers equipped with nothing fancier than standard word processing software could make a big difference. This teacher could access the students' essays in the word processor, use the computer to make marginal notes, and request a new and better version, iterating this process as many times as necessary to help the student rewrite the work until it represents the best work of which the student is capable. Then, and only then, the teacher would assign a grade. While such a process is certainly possible without the computer, the effort required of both teacher and student is prohibitive. But the computer takes the drudgery out, making better teaching possible.

This example illustrates, as well as any I can think of, the point made earlier: computers can simply add to the costs of instruction or they can be used to improve it. But this is simple-minded. In the following pages, we will see some much more creative ideas for using the computer to improve instruction, ideas submitted by teachers around the country asking for support from FIPSE in order to carry them out.

I am indebted to the FIPSE staff for their help in gaining access to these proposals, and to Stephen C. Ehrmann in particular, who has not only introduced me to many of the people who are doing the work described on the following pages, but has also been an invaluable colleague as I have tried to understand the significance of the developments described above.

University of Maryland

Daniel I. Fivel has been a member of the Department of Physics and Astronomy at the University of Maryland for 20 years. His proposal expresses much frustration at the tortuous way physics is typically taught and anxiety about how we can possibly teach what must be taught in the very fast moving field of optics, given the short time available to teach it. In an appendix to his proposal, he details the pedagogical significance of his photon state simulation program:

> [The . . .] computer will let us open up technical subjects to students at a much earlier age than was heretofore possible. We often teach subjects on a time schedule and in an order conditioned more by economic necessities than pedagogic wisdom. In the remainder of this narrative I will show just how this happens in the case of optics and how projects such as this can make an enormous difference.
>
> The usual method of teaching optics is to present it in the order it developed historically. It might be supposed that this is done because the phenomena investigated earliest were the most familiar and easiest to comprehend. The fact is that optics developed in the way it did because people didn't have strong light sources (like carbon arcs) in Newton's day and didn't have sensitive light detectors until the end of the nineteenth century. Strong light sources are needed to see interference (wave-like) effects if sensitive detectors aren't available. But if one gets the interference effects using strong light sources alone it is easy to arrive at the false conclusion that one is seeing true waves rather than wave-like artifacts of the photon's quantum mechanical nature. This is what actually happened in the nineteenth century, and it is why the history of optics is so convoluted. By teaching in the historical order we force students to learn one model (the Newtonian particle model), then unlearn it to learn the nineteenth century wave model (Maxwell theory), and finally unlearn that to learn our twentieth century photon model!
>
> One might naturally wonder why we haven't made those sensitive detectors and strong sources available to our beginning students and let them in on the truth right away. There are two good reasons: (1) Sensitive detectors and strong sources are expensive (though the latter are less so since the advent of lasers). They are also delicate and may be dangerous if improperly handled. (2) It is difficult to deduce the correct nature of light from the experiments one could reasonably perform in a school even if one had the money for the equipment and a great deal of spare time in the science program to devote to it. The computer, however, eliminates both of these problems by permitting us to quickly, vividly, and accurately *simulate* a multitude of phenomena. Indeed I first conceived this project when I found that to demonstrate a certain effect in my university physics course I needed an expensive tunable laser that our lecture demonstration facility (one of the best in the country) did not own. After some thought I realized that I could produce a simulation on the monitor for virtually nothing which would in fact give me more freedom to vary parameters and make the idea involved a great deal clearer.
>
> Thus by using computer simulations of light sources and detectors we will make it economically possible to introduce the beginner to situations in which the true nature of light is revealed rather than dancing his mind from one model to another on the end of an intellectual string. Moreover we will be able to simulate effects and manipulate parameters over ranges that would be unavailable with apparatus at any price.

Thus by using computer simulations of light sources and detectors we will make it economically possible to introduce the beginner to situations in which the true nature of light is revealed rather than dancing his mind from one model to another on the end of an intellectual string.

My computer simulations will allow me to place the strong sources and/or sensitive detectors in familiar and "comfortable" settings suitable, when desired, for even the most elementary level student. To appreciate this, consider the approach I may take to a famous question that sometimes occurs to observant children: "Why is the sky blue while sunsets are red?" To answer this I first allow the user to simulate the emission of blue photons and red photons from the sun on the monitor and use the simulated detector to watch how differently the blue and red photons scatter from an atom of

sky. The simulation will dramatically present the intrinsic randomness in the process, and seeing this the viewer will begin to develop familiarity with the way quantum mechanical processes operate. This scattering of sunlight can next be looked at using a simulated version of the eye of a bee as the detector—for it turns out that bees can directly detect the "spin" of the photon which our eye cannot. Finally different conditions in the sky can be simulated, i.e. the presence of different gases. Thus the dependence of the phenomena on the details of the interaction between photons and electrons in atoms are opened to investigation.

The quantitative description of various simulated phenomena can easily be adjusted to the mathematical maturity level of the student. A child can distinguish between blue light and red light, a college student can grasp the notion of momentum and spin of a photon, and a graduate student can finally comprehend the concept of a photon state vector. Correspondingly, the child needs no formula at all, the college student can manipulate Rayleigh's formula (obtaining some quantitative prediction about the color dependence of the scattering), and the graduate student can manipulate the full glory of the Kramers-Heisenberg formula (obtaining detailed predictions on how the scattering depends on the structure of the sky atoms). The point is that at all three levels the student will be using a correct, albeit simplified, model of the nature of light as we actually know it rather than a historic artifact.

Methods I develop in this project for simulating optical phenomena will immediately be applicable to some other important fields of physics. The most obvious candidate is the study of charged particles moving in magnetic machines which has a mathematical structure quite similar to that of optics.[10]

Earlier, in the body of the proposal, Fivel describes . . .

What the student will encounter and how the program achieves its objectives:

First the program permits the student to establish the sophistication level—elementary, intermediate, or advanced—at which he is prepared and/or desires to work. For reasons that will be more fully explained later, these levels will *not* correspond to the traditional division of optics into ray optics, wave optics, and quantum optics. Rather the three levels will correspond to the student's ability to deal with successfully higher precision vocabularies and more sophisticated mathematical tools.

Objective 1. Following his selection of level, the prompts will lead the student to tell the computer about the optical system he wishes to simulate on the monitor. He will be asked to choose words from a vocabulary offered by the computer, a choice which will result in defining the three ingredients found in all optical experiments: a light source, a material system with which the light must interact, and a detector.

The quantitative description of various simulated phenomena can easily be adjusted to the mathematical maturity level of the student.

On the elementary level, the light source vocabulary will contain words like "bulb" or "star" and the prompts will ask for further input to define location, brightness, and color of the source while offering "default" values for purposes of illustration. On the higher levels the light source vocabulary will contain words like "black-body emitter" or "NdYag Laser" and the prompts may ask the user to define the Kelvin temperature of the emitter or the mode and power of the laser.

Next the prompts will lead the student to define the material system. On the elementary level such words as "lens," "prism," "mirror," or "dust particle" will be offered. On the intermediate and advanced levels one will encounter "Fabry-Perot etalon," "diffraction grating," "lasing medium," and so on. Where necessary, the computer will once again ask the student for additional data about the material system, e.g. the focal length of a lens, the line spacing of a grating, and details of the atomic transition in the lasing medium. Finally, the detector will be specified by means of a range of words from "eye" or "emulsion" to "photomultiplier" with additional parameters requested as needed.

At this stage the student may request, and our program will display, a schematic layout of the system "designed" on the monitor. The geometric relationship of the source, material system, and detector will be represented in as accurate and

It is at this point that the basic idea of the project enters: the execution of the program uses the full power of the computer to calculate the passage of light through the system directly from the underlying laws of quantum optics.

vivid a manner as possible with the graphics capabilities of the computer. Moreover, the student will be able to refine his definition of the system manually using a joystick controller. Thus, if a lens is part of the experiment it will be possible to shift and/or rotate it. The computer will then automatically calculate and appropriately change the numerical values of any input parameters used to define the original configuration. In this way the student can "play" with the model on the monitor screen just as he would with equipment in the lab.

When the student is finally satisfied with his layout he will issue a command to "run" the system. It is at this point that the basic idea of the project enters: the execution of the program uses the full power of the computer to calculate the passage of light through the system directly from the underlying laws of quantum optics. In effect the program makes the computer do through mathematical manipulations exactly what nature does (or at least what our theory says it does).

As the run is executed, the monitor will display a simulation of the motion of the light from the source through the material and into the detector. This will be seen as a spot of light on the monitor travelling through the schematic layout of the system. An enhancement of the realism of the simulation will thus be achieved and build physical intuition.

Objective 2. The student may request any number of runs of the same system varying such parameters as he chooses, and my program will generate and display graphs of relationships between such parameters as may be selected. This will enable the student to probe the data and (perhaps with hints) discover the fundamental empirical laws. If a printer is also available he will be able to "dump" a hard copy record of data, graphs, and even a picture of the layout.

Objective 3. The next and more difficult task is to develop facility with the theory, specifically the ability to analyze and synthesize optical systems. Ultimately we want to create a practitioner—one who can calculate, predict, and (we hope) invent.

Understanding a physical theory requires a great deal more than merely knowing how to derive formulas from first principles. In particular the student must also learn to relate the formulas to the real world and use them predictively.[11]

Fivel goes on to explain his choice of the FORTH programming language on the basis of its capacity to reveal to the student the theoretical basis of the simulation, thus enabling the student to build up sufficient theoretical understanding of the phenomena to predict the outcomes of the experiments he constructs at increasing levels of sophistication.

Here we have a concrete and very creative illustration of the proposition encountered earlier that computers have the potential to change not only how we teach, but what we teach. Fivel's central concerns lie with his subject and with pedagogy, not with computing.

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Years ago, in *The Process of Education* (Harvard University Press, 1960), Jerome Bruner advanced the view that any subject, no matter how complex, could be taught at any level to students of any age in an intellectually responsible way. He advanced the notion of the "spiral curriculum" as a way of visualizing a curriculum structured so that the subject could be taught at increasing levels of sophistication in successive years. Fivel has devised a way to do just that for optics with the aid of a computer, which, you will note, is not programmed to teach optics, but rather to provide a tool that the student can use to learn optics.

Not the least of Fivel's accomplishments is the fact that he is doing this not with highly sophisticated raster-graphics-based machines, but with Atari 800's.

Colorado State University

Fivel's project certainly does require considerable programming skill. Harold Cochrane's idea for "An Experimental Program Incorporating Micro Computers into University Curricula" shows how standard off-the-shelf applications software can be used, once again, to change both what is taught and how:

> The purpose of this study is to experiment with different methods of incorporating microcomputers into a college curriculum. Macroeconomics will be taught to a class of thirty students using 15 Commodore computers. Because commercially available software will be exclusively utilized (VISICALC), most educators could readily adopt and modify the experiences gained through this experiment.

Integrating Microcomputers into the Classroom

Many experiences gained over the last eight years of teaching have led me to conclude that economics can be more effectively taught by asking students to use their imaginations. "Imagine being chairman of Federal Reserve." "Imagine owning a small company." "Imagine if you are retired and forced to live on a fixed income." "Imagine if you graduated and you want to buy a house." It has been my experience that a student's enthusiasm for the subject is directly linked to his/her ability to connect the theoretical with the practical. There are, of course, exceptions. The brightest students appear to be comfortable with abstract explanations and often surprise us with their ability to extend them to their own experiences. If such instances were commonplace this proposal would be unnecessary. Until recently, role playing in the classroom was limited. I could ask them to speculate, interweaving a few of my own personal experiences thereby strengthening the connection. This, of course, still leaves the instructor in the position of doing much of the imagining. I believe that if properly utilized, personal computers will prove to be an important key linking theory and application.

Many of the computer exercises I have reviewed require little in the way of student involvement. They are asked to enter responses and observe resuits but are not privy to the internal workings of the program. I believe that creating an exercise is more important than passively watching the computations unfold. It is for this reason that the VISICALC program proved to be so popular. It allowed users to create their own programs and to gain confidence in the results. Most important, VISICALC provided them some sense of mastery over the "machine."

It is for these reasons that I believe that the project is pointed in the right direction.

Learning Economics

I believe that the abstract nature of the discipline prevents a majority of students from either understanding the material, or more damaging, not believing it. Milton Friedman's claim that a model need be realistic to be useful probably does not apply to teaching. We have found that role playing is an important element in conveying theory. For example, money multipliers can be taught abstractly to derive formulas through the solution of geometric series. Or, the students can act out the role of a bank officer. They can set their own goals, use whatever economic signals they see as relevant, and make decisions accordingly. In almost every instance their own choices conform to that indicated by the more formal models. Once they see this relationship, the theory is no longer abstract but is viewed as a shorthand representation of their own behavior. Business investment decisions, stock and bond transactions, consumer spending plans, industry's pricing and output decisions, and government's policy choices all can be taught in a similar fashion. Role playing, of course, is a time consuming exercise unless computer assistance can be provided. The purpose of this project is to develop software to create a setting where these roles are as realistic as possible without making the exercises overly complex.

Emphasis of the Teaching Package

I have given much thought to how desktop computers can be integrated into the classroom and am convinced that the strategy suggested below is both feasible and desirable. Even though it utilizes the economics discipline as a focus, the lessons learned should also apply to other fields.

Many of the textbooks that are used in economics courses portray the economy in an oversimplified and somewhat antiquated light. The models are built on a conception of human behavior and technological advancement which is almost 20 years old. The computer revolution and its impact on information dissemination has not been systematically incorporated into economic theory. As a result, the models that are taught only explain tangentially the emergence of competitive finan-

Because I feel that expectations play a powerful role in almost every aspect of the economy, provisions will be made to treat them in the decision making exercises.

cial markets and resultant volatility of interest rates. The evolution of interest rate futures; indexed wages, bond prices, and social security payments; creative financing of mortgages; and creative ways of circumventing the tax code and banking regulations (NOW Accounts) are given scant attention. If they are treated, it is from the point of view that they are necessary terms the student must know. We are convinced that many of these changes could only have taken place as a result of inexpensive information processing. This of course is oversimplifying the case. However, we wish to distinguish our approach from that which has been traditionally taken.

Beyond this I believe that students are confused by the lack of focus exhibited in many texts. Not that a point of view is not apparent, but it takes almost 300 pages of theory to ask questions about policy. At this crucial juncture in our nation's economy there are only a handful of issues that deserve attention. Furthermore it is unlikely that these issues will change significantly in the near future. We intend to design the software to highlight six fundamentally important areas. They are:

1. *The Role of Expectations in the Economy*—The record tax cut of 1980 did not produce the desired results. The reduced rate was to have stimulated households to save a higher proportion of their income. This added savings was to have provided American industry with lower cost of funds thereby stimulating capital investments. The subsequent economic expansion was to generate enough new tax revenues to more than offset the fiscal effects of the lower rates. We know now that such a scenario did not come to pass. Was it because the tax cut was phased in over three years? Was it because government spending suddenly surged? We believe that neither of these is correct. It is more likely that inflationary expectations were tougher to break than the policy makers had anticipated. The tax cut in conjunction with tight monetary policy caused bond traders and lenders to be very cautious. They had learned their lessons in 1974 and again in 1979; making long term loans in an uncertain environment proved to be the undoing of a record number of savings and loans. Based on these experiences lenders were not enthusiastic about locking themselves into low interest long term loans. As a result, the housing and automobile industries were severely effected. The economy unraveled and the rest is history.

Because I feel that expectations play a powerful role in almost every aspect of the economy, provisions will be made to treat them in the decision making exercises.

2. *The Role of the National Debt*—Almost every first year economics student has been exposed to the following principle "the national debt is of little concern since we owe it to ourselves." We are now finding out that such an unqualified belief could lead to serious consequences. A large deficit can result in the crowding out of private investments and subsequently lead to a stagnating economy. The consequences of a perpetual imbalance in the federal budget for financial markets will constitute a major set of exercises. Linkages will be drawn to the role of expectations.

3. *The Vulnerability of the Housing Industry to Inflation*—Most textbooks treat inflation as if it were a nuisance. They demonstrate that, in the long run, misguided monetary policy will alter the level of prices and leave the economy at the same level of employment. They fail to disaggregate the effects. For example, the qualifying formula used by savings and loans incorporates the market interest rate and the applicant's current level of income. The former contains an inflation factor; the latter does not. The result is fewer and fewer applicants qualifying as inflation accelerates.

4. *The Role of the Fed in the Economy*—Nearly everyone today is watching the Fed. Investors are trying to anticipate FOMC actions. Congress is critical of its seeming unwillingness to expand the money supply enough to force interest rates down to an "acceptable" level. The Chicago School second guesses its strategy for maintaining an acceptable growth in the money supply (too erratic they claim). It is important to illustrate to the student the nature of the Fed's operation with specific reference to the above observations. These exercises are designed to demonstrate the pitfalls that are encountered. Is it desirable to focus on monetary growth or interest rates? If the latter is chosen then what are the ramifications? Can the Fed maintain the targeted values without inducing sizable fluctuations?

5. *The Role of International Banking*—Default on loans made to Mexico and Poland have triggered a number of financial scenarios depicting the frailty of the international banking network. The extent of the network needs to be highlighted and its sensitivity to domestic monetary policy illustrated.

6. *The Changing Population Structure*--Very few components of macroeconomics are tied to the age distribution. The "Life Cycle Hypothesis" which relates consumer demand to age of the household is the only one that readily comes to mind. This one exception does not alter the nature of the theory described in the average text. It is striking that solvency of Social Security is given scant attention, if any. Current tax rates and population forecasts need to be built into the course material.

Exercises

The program series will be comprised of three levels ranging from elementary principles of income expansion to an integrated decision making exercise.

Level I—This package will consist of several self-paced training exercises to acquaint students with the principles of macroeconomics. The following topics will constitute a minimum offering: 1) income multipliers, 2) commercial bank credit creation, 3) stock and bond price analysis, 4) Federal Reserve operations, 5) automatic discretionary fiscal policy, 6) international trade. Each program will lead the student through a series of exercises beginning with important definitions. Graphics displays will be used wherever feasible.

The laboratory's 16 microcomputers will be connected by a core program controlled by the instructor.

The student will be asked to anticipate how changes to any of the economic model's components will alter the outcome. In those situations where there are multiple levels of analysis, the intervening steps will be portrayed. For example, a student should understand how a change in tax rates alters disposable income, business inventories, and subsequently national income.

Level II—is designed to weave the preceding exercises together into a comprehensive framework. The Level II exercises will begin simply with an income and expenditure framework, expand to include the money market, and conclude with the addition of aggregate demand and supply.

Level III—is an interactive exercise which builds on the material learned in Levels I and II. The laboratory's 16 microcomputers will be connected by a core program controlled by the instructor. The students will be assigned roles similar to those assumed in the previous exercises, i.e., bankers, business planners, Fed FOMC, households, etc. The exercise will begin with a preset state of the economy; they will be asked to set goals and make choices. Realistic lags will be established for each activity, so initially they will be determining policy based on their best guess as to how the economy is performing. Money supply figures, price indices, federal budget information, trade statistics, and labor statistics will be made available to the class routinely. The purpose of the exercise is to demonstrate the difficulty in managing the economy when information is imperfect and the impact of decisions are not felt for a period of time. The class will experiment with a variety of monetary and fiscal strategies.

Applicability to Other Disciplines

The most important aspect of the project is a determination whether role playing games, interactive exercises, and student participation in the development of solutions enhances their understanding of the subject. The use of economics to demonstrate these points is not incidental but it is not essential either. I believe that other disciplines can readily adopt the broader lessons learned as a result of the project.[12]

University of Illinois

Earlier, in our description of events at Brown, brief reference was made to an experiment, in a poetry criticism course, with something called "hypertext." The basic idea for hypertext was first advanced in 1945 by Vannevar Bush, then science advisor to the President:

> The human mind . . . operates by association. With one item in its grasp, it snaps instantly to the next that is suggested by the association of thoughts, in accordance with some intricate web of trails carried by the cells of the brain. It has other characteristics, of course; trails that are not frequently followed are prone to fade, items are not fully permanent, memory is transitory. Yet the speed of action, the intricacy of trails, the detail of mental pictures, is awe-inspiring beyond all else in nature . . . Consider a future device for individual use, which is sort of a mechanized private file and library. It needs a name, and, to coin one at random, "memex" will do. A memex is a device in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility . . . when numerous items have been thus joined together to form a trail, they can be reviewed in turn, rapidly or slowly, by deflecting a lever like that used for turning the pages of a book . . . It is exactly as though the physical items had been gathered together from widely separate sources and bound together to form a new book. It is more than this, for any item can be joined into numerous trails.[13]

Bush's idea was brilliant, but years went by before the computer became available as a practical means of implementing it. In its present conception, hypertext could transform the way people who think for a living do their work.

To grasp what hypertext is, imagine that you are taking a course in the epic poem *Beowulf* at Brown. You turn on your computer and a page from a critique of a stanza of the poem by your professor appears on the screen. Reference is made to the stanza. You hit a key and the stanza appears on the screen. You look at the poem and the critique. A few lines down in the critique, reference is made to the work of another critic. You hit a key and the relevant section of the other critic's work appears on the screen. You decide that both your professor and the other critic have missed the point of the stanza. After hitting another key, you type in your own critique of the stanza in the computer's memory. Seeing another footnote later on in the professor's text, you examine the referenced work, then turn the computer off and go to dinner. Later that evening, your professor comes across your comment, decides that it is brilliant, writes you a congratulatory note, and then puts a flag in the program so that the other students in the class, when they next sign on, will read your analysis and his comment on it. He hopes that might spark a series of comments from other students on the passage in question.

Hypertext is a collection of text files in a computer, connected together by predefined links. Users can choose their own starting points and their own paths through these files. Both text and links can be added, deleted, and edited. If the files consist not only of text, but also visual images, sound, simulations, models, data sets, and so on, then hypertext becomes hypermedia.

In 1980, Don Thursh, director of pathology at the University of Illinois College of Medicine, and his colleagues began development of a hypertext-based "living textbook of pathology." Consider what this might mean. New knowledge in pathology can be incorporated in the students' text almost immediately, rather than with the usual delay of several years. The text need not predetermine the course of study since the sequence of topics and subtopics can be determined by any teacher or student. Exams can be embedded in the text, the answers evaluated by the computer, and the student routed to sections of the text that bear on the problems revealed by the test. Still and motion pictures can be incorporated in the text, providing illustrations often superior to those found in the printed text.

But it is much more than an up-to-date, flexible, multi-media text. Thursh and his colleagues are building in links to MEDLARS, the computerized national collection of medical research literature operated by the National Institutes of Health. So, from the user's point of view, this "textbook" will ultimately contain all of the nation's research literature!

What do we have now? A standard reference work on pathology? A textbook? A research library? An examination system? Clearly it is all of these things. But if it is all of these things, de-

The system would "know" what was in its files, would "understand" what you wanted to know, and would be able to "figure out" what it had that was related to what you wanted to know.

signed to be used by students, interns, physicians, researchers, and teachers, how could anyone predefine all the links that would be required in advance? Ideally, they would not be predefined at all. The system would "know" what was in its files, would "understand" what you wanted to know, and would be able to "figure out" what it had that was related to what you wanted to know.

And that is just what the project has set out to achieve. The University of Illinois team plans to manage the file with "semantic networks," a technique developed through work on artificial intelligence:

> The essence of the kind of semantic network we plan to use is the meticulous definition of the kinds of information that can exist and the possible relationships between these different kinds of information in general terms. In pathology, the kinds of information that exist include things like diseases, pathological changes, clinical signs, laboratory tests, experimental models, pathogenetic mechanisms, etc. The kinds of relationships that exist include things like causes of, manifestations of, sites of involvement, examples of, laboratory abnormalities in, etc. As we reorganize the knowledge-base in pathology to apply the semantic network, we will add to each segment of it a machine-readable statement defining the kind of information contained in that segment. This, together with the machine-readable key-words that are already part of the knowledge-base, will allow the computer to always "know" where it is, be able to "deduce" what other kinds of information the user may want next, and "interpret" requests for additional information on the basis of rules defining relationships within the network that will be developed.
>
> When The Living Text is implemented as a semantic network, access will be user-defined on the basis of the key words and relationships between key words selected for study. This will allow individual users much greater freedom in how they move about and acquire information. For example, a user studying glomerulonephritis, a *type of disease* of the kidney, might decide at some point that he/she wanted to see all the available information on *laboratory tests* of kidney function. At present he/she would have to return to the index or table of contents to access this information, much as would have to be done with a conventional textbook. When the semantic network has been created, however, the network will "know" the relationships that exist between *laboratory tests* and *organs* and between *types of disease* and *organs*. From the key word *glomerulonephritis* it will be able to "deduce" that the kidney is the relevant organ and therefore "know" exactly where to look for the information requested.
>
> The basis of the computer's "knowledge" will be a series of very detailed general hierarchies describing how different kinds of information, e.g., diseases, organs, manifestations, laboratory tests, pathogenetic mechanisms, pathophysiological effects, etc. can be interrelated in the study of pathology. The information that glomerulonephritis is a *type of disease* will be explicitly linked to the key word glomerulonephritis. The "deduction" will be based on finding the key word for the *organ* most closely related to glomerulonephritis, i.e., the kidney.[14]

The pathology living text was originally implemented on a large mainframe computer but is now being moved to a VAX 11/780, a machine in common use on our college and university campuses. Such hypertext-based systems could be developed at many institutions, transported elsewhere, and linked together. Or they might be developed at a few institutions, and the product sold to others who use them through telecommunications links. The Illinois team originally "wrote" the text itself, but is now drawing on experts in pathology from all over the country. It is unclear how many such efforts the country will be able to support in each field. The economies of scale that could be achieved appear to be great, suggesting that, as a nation, we will be better served by having a few very elaborate systems rather than many systems with fewer files and less powerful management systems. Like the developments described in the first section of this *Current Issues,* hypertext seems to be another factor with potential for changing the structure of higher education. In this case, however, those who take the lead need not necessarily invest tens of millions of dollars—at least at the outset—nor undertake to remold an entire institution.

Milwaukee Area Technical College

We turn now from the training of professionals to the training of technicians. Hard hit by foreign competition and factory automation, Milwaukee industries are working collaboratively with the Milwaukee Area Technical College (MATC) to develop the cadre of technicians they will need to compete effectively in a manufacturing environment dominated by computer-aided-design (CAD), and flexible manufacturing systems (FMS).

MATC worked hard to gather data about regional labor needs and to develop close working relations with employers. The College intends not only to train recent high school graduates, but also to provide a substantial program of retraining for those laid off by old line industries as well as those fortunate enough to hold jobs in growing firms. Much of the equipment being used in the school was donated by their industrial partners. Perhaps more important, the firms they are working with are helping them to define the curriculum and will evaluate the program and its graduates to make sure that the curriculum achieves the goals that were set.

The design of the program is built around computer-based labs that will simulate the operating environments in the industries in which the students will work.

Here is how the College describes its program:

I. Statement of Need

A careful examination of scientific hardware and modern industrial processes reveals complex systems that may be composed of combinations of electrical, electronic, mechanical, pneumatic, hydraulic, thermal, and optical devices. The person who works with high technology equipment and systems must have a broad technical background to deal with the variety of technology effectively. The greatest need is for the "super tech" who can install, operate, maintain, and repair systems that may incorporate combinations of electrical motors, digital circuits, mechanisms, hydraulic actuators, lenses, light sources, and transducers. Many of these systems are controlled by microcomputers and are part of huge computerized data bases requiring persons skilled in information management, including documentation development, storage, retrieval, and decision making. Persons with interdisciplinary skills and knowledge do not just emerge. They must be prepared through well-designed programs that include the broad knowledge bases required to apply the needed interdisciplinary skills.

A broad understanding of basic principles in the various functional areas of high technology will guarantee that the technician has flexibility to meet the requirements of tomorrow's technology. If the job is fairly repetitive or hazardous, it is quite likely that it will be performed in the future by industrial robots. But this situation does not mean that this displaced worker will no longer be needed. The worker obviously knows more about the requirements and skills of that specific job than anyone else. Logically then, the displaced position would re-emerge as a "technical supervisor" of a crew of five or six industrial robots. We believe that such workers can be promoted and technically upgraded if they are willing and able to retrain for the technical aspects of their new jobs. In the high technology occupations, however, this means extensive retraining in broad technical principles and equipment and not just a six week "quick fix" course on how a particular robot works.

The person who works with high technology equipment and systems must have a broad technical background to deal with the variety of technology effectively.

The need for new skilled workers in the emerging information management occupation has been forecasted based on the number of computer graphics systems installed in the Milwaukee area. The first survey in 1977 was conducted by telephoning over 90 industries; 23 computer graphics systems were located. In 1981, a survey completed by the Wisconsin Chapter of National Computer Graphics Association located 49 systems and by 1982 this had grown to 88 systems. With an estimated four computer-aided drafting (CAD) operators per system and an average of 1.5 shifts there should be 528 jobs, and with a 20% turnover plus a 30% growth rate per year a need for 263 trained persons is projected for 1983. This does not include students, business persons, engineers, computer-aided manufacturing persons,

graphic arts or television personnel, or other users in other fields. The need for CAD training in these added areas plus training in manufacturing automation and information management technologies easily moved local need to over 1000 persons per year. The waiting list grew to nearly 500 persons for one CAD course in the fall of 1982.

The Metropolitan Milwaukee Association of Commerce (MMAC) Skilled Labor Task Force reported that metropolitan Milwaukee's strong industrial base would be threatened unless a much larger pool of knowledgeable workers became available.

This proposal describes the objectives and timetable for development and implementation of cost-effective solutions to high technology education. Industrial partnerships, open resource centers for maximum scheduling of expensive student stations, microcomputer emulation of costly industrial systems, and courseware will all contribute to efficient use of resources.

Faculty will be given the opportunity to improve their skills in computers and automation techniques through workshops and courses taught by industrial adjunct faculty, external consultants, and by our own faculty who have attended workshops. Faculty selected to become involved in the project will be in high priority areas and will have voluntarily obtained CAD training, successfully developed curriculum materials, and will have had active industrial relationships. The re-training of these faculty members emphasizes development of closer relationships with industry, working on industry sub-committees, teaching beginning technology courses, teaching one day specialized mini-courses, and eventually, advanced technology courses.

The program will continue over three years. The emphasis in the first year will be to expand computer-aided-design (CAD) skills within automation courses and develop curriculum to include new programs and courses for automated manufacturing, electrical design, and information management. Emphasis in the second year will be to offer the newly developed or revised automation-affected programs and courses. The third year activities will be to complete the implementation of the advanced courses in the new or revised automation programs and the evaluation and dissemination of materials. (It will take three years to retrain staff to advanced levels).

The hub of development will stem from the MATC Computer Resource Center which is equipped and staffed to support CAD and computer application development. The automation process and planning will most likely be developed at a CAD work station and this is why centralization of support in the CAD center is planned. For example, direct computer numerical control (DNC) programming is performed at a CAD station and proved out in the flexible manufacturing system (FMS) lab just as drawings are created at a CAD station and proved out in a plotted drawing.

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Resource activities will be available 80 hours per week for open access to students, faculty, and industry persons for individual study and for technical assistance with high technology workstations. The existing CAD center will emphasize continued development of engineering design programs and courses. A new program in electronic design and packaging will be developed and begin in 1984, while the existing programs in mechanical, civil, and architectural technologies will expand their offerings with advanced courses and assignments integrated within other courses. The computer applications development to support the FIPSE activities will be centralized here.

The first priority proposed is to develop a new resource center and curriculum to support the major need of automation manufacturing and metal working industries, utilizing a technique developed by industrial and manufacturing engineers called FMS. FMS is a designed and integrated group of automated manufacturing equipment that can include numerical control machines, automated material handling equipment, automated assembly equipment, robots, and utilize programmable controllers or a central computer source.

The robots, NC machines, etc., would relate to business planning, manufacturing planning, shop floor monitoring systems, and process automation [in] a simulated factory of the future. U.S. industry requires greater numbers of workers who have been trained in the design, management, set

The first priority proposed is to develop a new resource center and curriculum to support the major need of automation manufacturing and metal working industries . . .

up, and maintenance of the components of FMS and understand the interface requirements. Numerical control is one of the first steps in manufacturing automation and CAD is a first step in engineering automation. FMS will serve the manufacturing automation program, which is planned to start in 1984, and the new courses integrated into industrial engineering, welding, numerical control, and electrical programs.

The second new resource center planned for development, the Graphics Communications Center, is to support another key Milwaukee area industry facing massive automation growth in the area of graphics design and publications. The design of computer graphics and electronic images for printing, advertising, industrial photography, and television will include the automation of both input and output processes available for the respective occupational program areas. The center will serve the need to upgrade local employees shifting from manual to automated processes [and] regular full time students.

The development of an information management element to serve the various industries will utilize support of an existing information processing lab and industrial engineering program. The needs of business and industry in the FMS area, graphics communications, and CAD areas, require information management courses and workshops as well as an information management continuing education program. This upgraded program is planned to maximize use of word processing, data processing, and telecommunications for efficient business and industrial operations.

The continuing education element is vital to developing viable courses for full-time students. Employees seeking retraining in the same classes with full-time students being trained for entrance into similar occupations, creates an environment for learning not possible with only full-time students.

Because of the high attraction level of high-technology courses, the new courses offered in the automation areas will be made up of about 70% continuing education for employee skills upgrade and 30% enrollment consisting of regular MATC full-time students. As seen in the past, enrollment is expected to fill all offered sections and result in a substantial waiting list. The first CAD course offered resulted in enrollments of 475 persons per year with a waiting list of 500 persons at one time. Recruitment is expected to be low key at first until adequate capacity is developed.

The Wisconsin State Board of Vocational and Adult Education has allocated MATC $114,000 of Vocational Educational Amendment funds to obtain high technology equipment. MATC has a successful record of obtaining needed technological equipment from industry through industrial partnerships. Since 1980, Computervision Corporation has donated two CAD/CAM systems valued at $1,038, 511; World Book has donated computerized text editing systems valued at $270,490; Cadlinc has donated two Microcomputer CAD systems valued at $95,240; Mergenthaler Co. donated a computerized phototypesetting system valued at over $250,000; and Hell Co. has donated two laser scanners valued at over $225,000. We have received $27,500 in cash donations from local industry to help acquire other equipment. Much of the equipment needed is already in place, and future donations will upgrade and/or expand the system. Equipment becomes obsolete in many cases within three to five years and continuous efforts to upgrade are planned.

Our past development efforts in CAD have resulted in an emulation of the Computervision system allowing us to teach CAD on a $3,000 microcomputer. It was previously taught on a single $100,000 industrial design station. The MATC developed software and courseware has created a demand from over 300 organizations from Connecticut to California, all before the official software release announcement. MATC is well equipped, recognized as a leader in CAD, and is in the best position to continue developing cost-effective high technology educational materials for nationwide use. The evaluation component will consist of the following, to be submitted to and reviewed by the steering committee for the project: (1) measuring efficiency of student station scheduling; (2) annual student enrollment data; (3) student achievement of objectives; (4) student survey upon course completion; (5) student follow-up after employment; (6) faculty assessments regarding improvements in teaching scientific and engineering principles; and (7) use of the steering committee consisting of representative industry technical employers for reviewing and making recommendations on relevance of curriculum and effectiveness of training.[15]

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Commentary

The account of the program at Milwaukee may seem oddly out of context, quite unlike the other descriptions, which focus on the uses of the computer in the arts and sciences and in professional education. Often, when we think about computers and training, we assume that the computer will be used to train in a traditional computer-assisted-instruction (CAI) mode. At MATC, there may be some CAI, but the object of the game is mainly to help the student understand the complex roles that computers are playing in the design process and in controlling highly automated manufacturing operations. Clearly, the people at MATC believe that the best way to teach people how to operate and maintain such systems is to put them in an environment where they have access to systems very much like those they will be using later on, and help them become proficient users of those systems.

This sounds very much like Carnegie-Mellon's definition of computer literacy.

For me, "computer literacy" means learning how to use the computer as a tool to get one or more tasks done that you need to do. What you need to learn depends on the tasks you want to accomplish with it. Because tasks vary widely, it is inevitable that the skills one has to learn will vary widely, too. It follows that the meaning of computer literacy for me will almost certainly be different from the meaning for you. From that it follow that the attempt to define a universal set of skills in the name of computer literacy is fruitless. In a college setting, the trick is to think about computer literacy, not in the abstract as a set of skills somehow disembodied from what is learned in the rest of the curriculum, but rather as a set of skills that grow out of using the computer in the context of the curriculum, as a tool for research, writing, organizing one's thoughts, and communicating with others.

The word "literacy" is misleading in this context for two reasons. First, it leads one to the notion that we ought to be able to define a universal set of skills that constitute mastery of the machine. And, second, it leads one to the view that the way to master this tool is to master the language it speaks, when, in fact, most people who will use it to great advantage will never need to program the computer.

Similarly, "faculty development" is an unsuitable term. The uses to which faculty will and should put the computer and telecommunications systems will be as varied as student use. There is no universally effective faculty development program any more than there is a universally valid concept of computer literacy, for the same reasons. What is important—and difficult—is to provide for each faculty member a source of help or technical assistance that will help that faculty member learn how to use information technology in ways that are congruent with his or her own objectives and working methods. Incentives here are surely as important as training resources. How many times have I been asked by administrators what faculty development program they can use to get their faculty to use computers, only to find that the administrator has no computer on her desk and has not the foggiest idea how to use one! Conversely, I have noted that when administrators turn to electronic mail as their preferred mode of communication, computer work stations sprout full blown on the desks of deans and department heads, who learn to use them fast, without benefit of highly structured staff development programs. The availability of training programs is an important, but by no means the most important, element in persuading and helping faculty to make the best use of computers and telecommunications.

Strong incentives are on the way. The authors of the documents collected for this *Current Issues,* from Providence to Milwaukee, have recognized that computers and telecommunications systems are on their way to radically transforming the way work gets done in our society, and they are prepared to make commensurately radical changes in their own modes of operation to be sure that they will be in a position to have something to teach that others want to learn, as well as an approach to teaching that enables both student and teacher to make the most of the time they have together. These are old goals. But we now have much more powerful means available to achieve them.

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